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SIMULATOR STUDY
OF
GEMINI BOOST ABORT SITUATIONS

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## FOREWORD

The basic objective of this study was to obtain a qualitative evaluation of the pilot's ability to observe displays of contingency information and reliably make abort decisions in the Gemini spacecraft. The results of the study are so reported in this document. However, in the interest of providing a brief but still comprehensive report, the following obtained quantitative data used in further substantiation of the results have been omitted from this document. This information may be obtained upon request from the study contractor.

- -- Typical vibrations experienced by two subjects during the establishment of the vibration profile as reported herein.
- -- Per cent successes vs. the total number of runs simulated for each malfunction problem.
- -- Per cent error score by subject by malfunction run.
- -- Subjective evaluation of response cues by subject.
- -- A typical randomization schedule of runs for one subject.
- -- The standard deviations of the means for each of the 23 malfunction runs simulated.
- -- A brief description of the application of the study results to the population of astronauts in general and to modified cockpit designs.

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# 1.0 SUMMARY

Results of the Gemini Boost Abort Simulation Study indicate that pilot monitoring of the booster systems with manual abort capability is a logical extension of aircraft piloting and escape procedures. Critical booster malfunctions were readily apparent through multiple cues such as linear or angular accelerations, noise, and cockpit displays.

In contrast to aircraft practice, the study showed that escape from rocket-launched spacecraft is more straightforward because the precise relations between time, dynamic pressure, altitude, and staging events enables definite pre-determined abort procedures.

An important aspect of the manual abort study was the elimination of inadvertent and hazardous aborts which would have resulted from malfunctioning automatic sensor circuits or sensor limits which, to avoid complex instrumentation nonlinearities, were set too conservatively (e.g., fuel and oxidizer pressure MDS settings). Additional gains in reliability and simplicity should be realized by eliminating the spacecraft and booster automatic sequential systems and providing manual control of the events after the malfunction begins.

There were only a few malfunctions which required an extremely fast reaction time. The study showed that manual abort was possible within one second of the onset of such failures.

# 2.0 INTRODUCTION

## 2.1 Statement of the Problem

The ability of the Gemini pilot to observe displays of contingency information and reliably make abort decisions should influence the design of the malfunction detection and escape initiation system and the integration of man in the overall system. Furthermore, the effectiveness of these systems reflect directly on the safety of the pilot and his ability to recover the spacecraft from conditions of emergency. It could also have a direct bearing on achieving an overall abort system of minimum complexity and maximum reliability. In pursuit of these objectives the initial simulation study reported herein was conducted to obtain a qualitative indication of pilot responses to a variety of abort situations which could occur during the boost phase of a Gemini mission. The investigation was conducted in response to NASA Contract No. NAS 9-255.

## 2.2 Objectives and Scope of the Program

The basic objective of the program was to obtain a qualitative evaluation of the pilot's ability to read and interpret displays of contingency information and their associated sound and motion cues, and make proper abort decisions. Specifically, measurements were taken of the pilot's total response time to interpret a display presentation and to actuate a "D" ring simulating abort initiation. The study was an open loop type in that the subject did not control the flight path or motion of the simulator in any way. His basic task was to monitor the displays, make decisions in the face of impending catastrophies, and actuate an abort handle, simulating escape from the vehicle either by seat ejection or capsule escape. His only other task was to position a mode selector switch to either seat or capsule escape.

All simulated abort situations were extracted from the results of an analysis of failure modes of Titan II. It should be emphasized that both the booster and spacecraft hardware were in the design phase at the time this study was conducted. Subsequently, several of the design features, operational procedures, and cockpit displays have been changed.

In establishing the pilot response times required for abort action, it was necessary to make several assumptions regarding vehicle dynamics. These assumptions may be pessimistic based on actual vehicle performance data.

# 3.0 METHOD

## 3.1 Titan II Malfunction Analysis

To determine the most desirable abort situations to be simulated during the study, a thorough malfunction analysis of failure modes of a Titan II booster was conducted, based on data presented in References 1, 2, and 3. Each failure mode was analyzed to show the series of events which take place in real time from the onset of the malfunction to catastrophe, the latter being defined as a "fire ball". The results of this theoretical analysis are presented in Appendix A.

From the analysis, eight major types of malfunctions were selected for investigation through simulation. Variations in the modes of failure within each type of malfunction resulted in the programming of a total of 23 distinct malfunction runs to ensure a reasonable sampling of pilot behavior in response to the more critical failures. In addition, a no-malfunction normal boost run was included which is not shown in the table below. These runs, listed as follows, were verified by the NASA prior to executing the experiment.

TABLE I

TYPE AND NUMBER OF MALFUNCTION RUNS SIMULATED

| Problem* | Type of Malfunction | No. of Runs |
|---|---|---|
| I-1 | Partial loss of thrust - one engine (1st stage) | 1 |
| II-1, 2 | Total loss of thrust - one engine (1st stage) | 2 |
| III-1, 2 | Total loss of thrust - both engines (1st stage) | 2 |
| IV-2, 3 | Hardover engine (1st stage) | 2 |
| V-1, 2, 3 | Staging failures | 3 |
| VI-1, 2, 3, 5, 6, 7, 8, 11 | Tank (fuel and LOX) pressure losses | 8 |
| VIII-1 | DC power failure | 1 |
| IX-1, 2, 3, 4 | Instrument warning light failures | 4 |
| | TOTAL NUMBER OF RUNS | 23 |

*Problems are identified as shown in Column 1, Table A-1, Appendix A

The selection of malfunction runs to be simulated was based on (a) their probability of occurrence, (b) their severity if they occurred, and (c) pilot response time requirements. In relation to the third criterion, those runs on which the data indicated the pilot could clearly diagnose his situation and abort at "leisure" were eliminated. A counter clockwise roll malfunction following lift-off in which the pilot has at least 14 seconds to abort, is one example. There was one run eliminated in which the analysis showed a required response time of 0.02 seconds which is unquestionably beyond human capability. This was the case of a hardover engine gimble just off the launch pad.

It should be pointed out that all runs requiring stage 2 fuel and LOX monitoring during first stage burning (Problems VI-4, 9, 10, and 12, Table A-1, Appendix A) were eliminated on the basis of information received from the NASA subsequent to the theoretical malfunction analysis and while the initial experimental runs were being conducted. Malfunction data was not available to determine the possible modes of failure of the second stage while in operation thus precluding the simulation of any such failures during the study.

## 3.2 Experimental Design

The basic scheduling unit for each pilot participating in the program was forty trial runs per day. These forty trial runs were composed of: (a) a minimum of one run each of the 23 malfunction runs, (b) a repeat of certain runs judged to be most serious or probable, and (c) four normal boost runs. All runs were randomly distributed for each individual pilot such that the subject had no way of knowing which problem would be presented next. Since the experimental design placed no restrictions on the order of occurrence of any particular problem, a multiple presentation run might follow itself.

Measuring the pilot's total response time from malfunction onset until the D-ring had completed its travel -- signifying completion of the abort action, was central to the study. Equally important was to obtain a measure of his ability to make the correct decision for each simulated malfunction, i.e., to determine whether or not an abort was required. Results of both these measures for all subjects are reported in the Results and Discussion section of this report.

The simulation set-up was programmed such that the pilot could not abort (i.e., terminate) a normal boost or a malfunction run which was not programmed to result in catastrophe. Even though he erroneously pulled the D-ring, the boost continued. If the decision to abort was correct, the pilot's activation of the abort handle stopped the computer which terminated the action of all displays, noise, vibration, etc., and returned the gondola (i.e., cockpit) to its launch position. If the subject did not respond to a malfunction which was programmed to result in catstrophe, the run continued from five to eight seconds beyond the catastrophe limit where it was terminated by the experimental controller. The subject was then immediately notified of his decision error. In all cases where the pilot pulled the D-ring in response to a malfunction catastrophic run, his total response time from malfunction onset was recorded by the computer flexowriter. Immediately after the run, this time was also reported verbally to the subject together with the time that was available for executing abort. The experimenter was then required to re-load the computer in preparation for the next run by positioning a re-set switch on his control console.

The experimental controller was supplied with a simplified console containing a minimum number of switches, indicating devices, a clock, etc., for controlling the study; plus a communications system which included both head phones and a loud speaker system for communicating with the subjects and a tape recorder for recording pilot's comments.

No information or advice was advanced to the subject on any run -- once the run had started, except Problem I-1, Partial Loss of Thrust of one first stage engine and its couterpart run, Problem X-1, a Light Malfunction. Near the end of the experiment it was decided that confirmation on these low altitude malfunctions from ground control would be realistic. Thus, when the pilot reported chamber pressure light onset and asked for confirmation or denial of loss of thrust, the controller replied "affirm" if the abort condition was I-1, and "deny" if the situation was IX-1.

## 3.3 Subjects

Subjects participating in the study were three Mercury Astronauts, two engineer-pilots from NASA, and one Vought test pilot, making a total of six in all. Several weeks before the experimental runs began all subjects were furnished pre-experimental study material as shown in Appendix A. Upon arrival at Vought they were introduced to the situation in which they would participate and encouraged to ask questions. It was felt they should be as familiar as possible with the experimental environment since they did not have sufficient time for thorough pretraining. The sole type of information withheld was the order in which experimental runs would be administered, the type and number of abort and non-abort malfunctions to be presented, and how many normal boosts they would receive.

After completing his experimental runs, the Vought test pilot supplemented the information given to the subjects during the inter-trial interval with more technical data where he deemed it necessary thus enhancing the information input to the subjects.

## 3.4 Experimental Procedure

To further acquaint each subject with the simulator set-up, the instrument panel, the noise and motion cues, etc., and their interaction, a series of representative runs were presented prior to the beginning of the experimental schedule. The fixed pretraining program presented to all pilots consisted of two normal boosts followed by Runs I-1, II-1, III-1, IV-2, V-2, V-3, VI-1, VI-2, VI-5, VI-6, VI-8, VI-11, VIII-1, and IX-2 in the order presented. All were identified before the fact to each subject. At his request any of the runs were repeated.

Following the pretraining session, a measure was taken of the time required by each subject to pull the D-ring. For this test the subject was seated in a horizontal position and secured in the cockpit with only the lap belt. He was instructed to pull the D-ring as rapidly as possible each time the "No Stage" light came one. The interlight internal was variable (ranging from 10 seconds to 1.5 minutes) thus no expectation of the light onset could be formed by the subject. The light went off when the D-ring was pulled. A mean basic response time for all six subjects of 0.42 seconds (with a range of 0.36 to 0.45 seconds) was measured.

Following this measurement, the experimental runs began by first presenting a normal boost to the subject to restore a conceptual picture of the indications and cues of the "eventless" run. The pre-boost procedure for all experimental runs was exactly the same:

(1) Subjects were advised by intercom that "Control is go".

(2) Subjects responded that the "Cockpit is go" meaning that the digital timer on the panel was reset to zero, the escape mode selector switch was in the Seat Eject Position, and the subject was ready for the next trial run.

(3) The experimental controller positioned a T-10 switch on the control console while simultaneously saying "T-10 and counting". A timer set at 10 seconds from time zero was started by the T-10 switch. At T-3 seconds the computer started through its program beginning with a simulated ignition of the booster provided by a noise tape. Lift-off was initiated at T+ 0 with an increase in noise simulation and a rapid gross pitch increase of the gondola.

## 4.0 MECHANIZATION OF SIMULATION

The hardware components for the simulation consisted of a combination analog-digital computer, a moving base cockpit simulator and selected physiological measuring equipment. The cockpit simulator contained an instrument panel, seat vibrator, high fidelity noise reproducing equipment, D-ring abort handle, and a horizon-starfield projector. In the interest of clarity of understanding, the instrument panel is discussed first.

### 4.1 The Instrument Panel

Figure 1 shows the instrument panel configuration used in the study. Only those instruments which were thought to be necessary in making abort/non-abort decisions were provided. They are described as follows:

Attitude Display - This display was simulated by a cathode ray tube tracing pips for a horizon line, roll degrees, pitch degrees, and pitch, yaw, and roll rates. Limits for all rates were red lined on the scale indicators for both first and second stage. In addition, the warning lights associated with each of the rate displays lighted up the moment the indication exceeded the redlined limits. These respective rate lights were set to flash on above $4.0^{\circ}$/sec. for the first stage pitch and yaw and $10^{\circ}$/sec. in the second stage. The roll rate light flashed on at $12^{\circ}$/sec. in both stages. A separate dial was provided immediately below the main attitude display for indicating yaw degrees.

Tank Pressure Displays - Tank pressure indicators (marked 1 and 2) were used for monitoring both first and second stage booster liquid oxygen and fuel tank gaseous pressures.* The associated pressure warning light came on whenever the pressure in either the LOX or fuel tanks went below a given psi.

Chamber Pressure Indicators - These lights were programmed to go off when engine combustion chamber pressure reached 65 per cent of normal thrust. The Chamber 2 Light was programmed to stay on throughout first stage boost. Under normal operating conditions the Stage 1 Chamber Light remained off.

Clock - The clock was not operative during the study. A digital seconds counter (not shown) was substituted and mounted above the Abort Mode Switch.

Abort Mode Switch - This switch which was placed in the "Seat" position before each boost was re-positioned to the "Capsule" escape mode by the pilot at T+100 seconds. The subject was required to report his change of mode during each flight.

Accelerometer - This dial, graduated in g-units, displayed the amount of axial acceleration programmed to be acting on the vehicle during boost.

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*All Stage 2 monitoring functions were subsequently eliminated during the study (see Section 3.0).

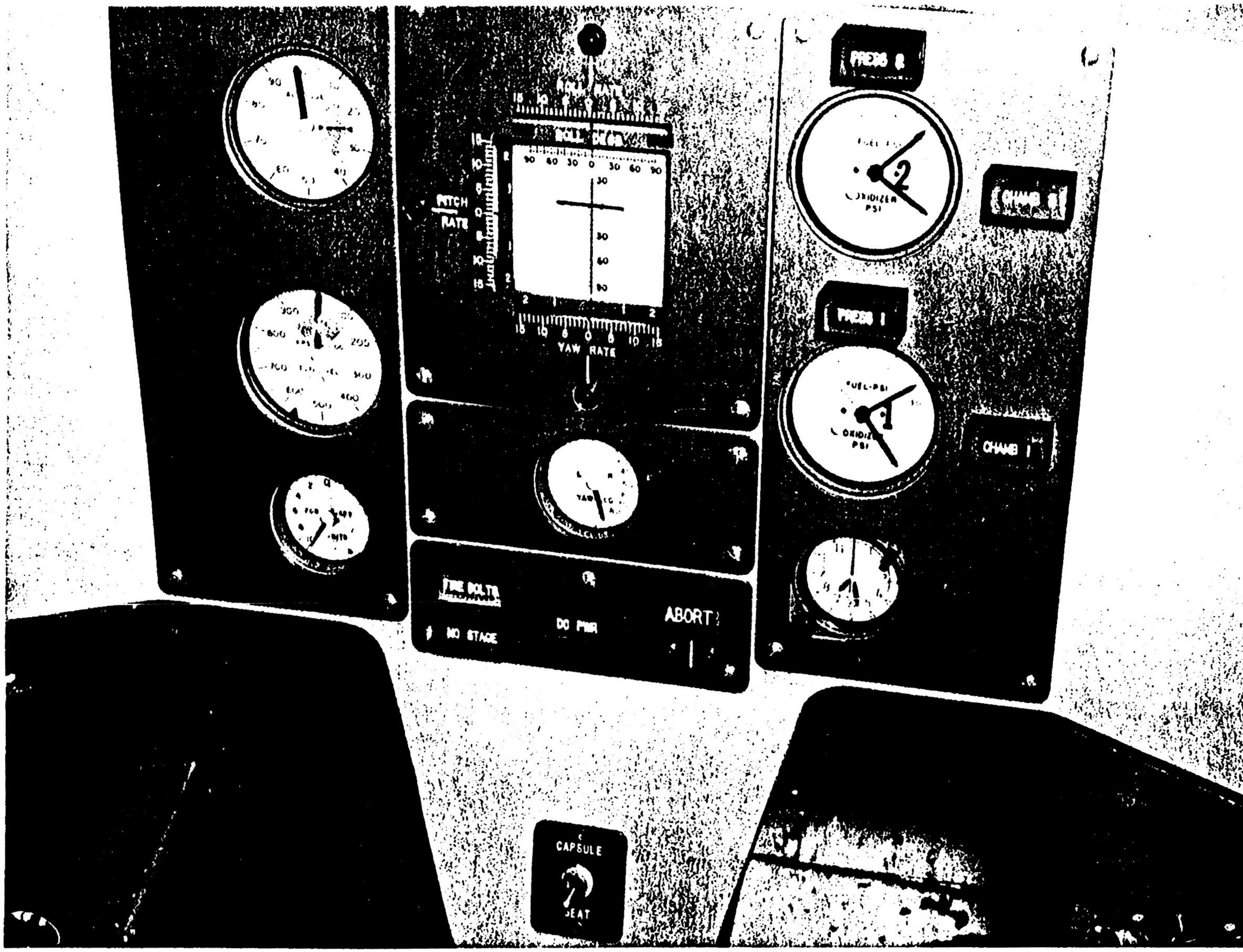


FIGURE 1 – INSTRUMENT PANEL USED IN THE STUDY

Velocity Indicator - The main dial of this instrument was graduated in 10 fps increments while the inset dial was graduated in 100 fps units.

Altimeter - Used only as an indication of mission status, the main dial was graduated in 1,000 ft. increments while the inset dial was graduated in 10,000 ft. units.

Fire Bolts - This indicator was programmed to come on at simulated staging, T +148.0 seconds. It was assumed that the signal which energized this light also ignited the second stage.

No Stage - This light was set to come on 2.1 seconds following activation of the Fire Bolts light or 1.4 seconds after the Chamber 2 Pressure light went off if separation of the two stages had failed to take place. It was assumed that activation was initiated by a timing circuit which was physically interrupted by separation of the two stages.

D.C. Power - This light came on whenever D.C. power for the vehicle controls fell below 26 volts D.C.

Abort Indicator - This complex came on whenever the D-ring reached the top of its travel as an indication to the pilot that he had pulled the D-ring to its limit and whether or not the mode of abort was correct. This light was used for film recording.

The panel had no internal illumination and so depended upon ambient lighting. With the exception of the green Fire Bolts light, all warning lights were red.

## 4.2 Computer - Flight Simulator Arrangement

The following is a description of the computer-flight simulator setup, the equipment used, cockpit motions, noise generation equipment, etc.

Drive Mechanisms for Instruments and Warning Lights - The altitude, velocity, acceleration, heading and tank pressure instruments as shown in Figure 1 were syncro driven. This was accomplished by appropriate digital to analog conversion of the time variant driving functions. The analog signal positioned the shaft of a servo on which was mounted the driving coil of the synchro. Signals for the warning lights were converted to analog voltage levels which were sufficient to throw a relay; the relay then provided 28 volts D.C. to operate the light. The signals for the three angular rate warning lights were directly dependent on the rate time functions and were produced by means of a biased absolute value circuit built up with operational amplifiers, semi-conductors, potentiometers and relays. The CRT display required analog signals for pitch, pitch rate, roll, roll rate and yaw rate. A time sharing technique was employed to produce all of these indications with a single CRT.

Cockpit Motions - The moving base simulator cockpit used in this study had three degrees of freedom in pitch, roll, and yaw with displacement capabilities which corresponded to the small perturbations of the normal flight path. A gross pitch rotation of $\pm 100^{\circ}$ from the horizontal permitted a reasonable simulation of the direction of axial accelerations. The cockpit motions and seat vibrations were accomplished by hydraulic servos driven by analog signals. Figure 2, which was patterned after an Atlas MA-2 flight spectrum supplied by NASA as a guide, illustrates the oscillations vs. time which were applied during the standard boost run. The basic sinusoidal signals were built up with operational amplifiers and potentiometers and were switched in and out using time data from the digital computer. Peak accelerations, as shown, were measured with accelerometers attached to the cockpit seat. Additional steady state or sinusoidal accelerations as required for simulating those motions relating to vehicle malfunctions were applied to the pitch and yaw parameters. Roll accelerations associated with the malfunctions were considered too small to be of any reasonable consequence.

For the standard boost profile (Figure 2), a vehicle lift-off disturbance of 3 cps occurred in pitch, roll, and yaw as well as longitudinally, for one second. From T + 3 seconds to T + 17 seconds a 5 cps vibration occurred in pitch, roll, and yaw. The pitch vibration (effected through the seat) peaked at 0.4 g. Also during the T + 3 to T + 17 time interval, a 5 cps vibration occurred along the longitudinal axis and peaked at 0.3 g.

From T + 80 to T +105 seconds a 1 cps oscillation occurred in pitch, roll, yaw, and longitudinally which represented an instability in the vehicle during high "q" flight. At T +149 seconds a mild oscillation (1 cps at 0.05 g) occurred for one second in pitch and yaw representing a disturbance caused by stage separation. Throughout all simulated flights the seat vibrator maintained a low amplitude 20 cps vibration representing an assumed structural "noise".

The gross pitch was rotated up to 57° from the horizontal for the launch position which produced the sensation of the pilot lying on his back ready for boost. At lift-off it was rotated from 57° to 75° within one second producing the sensation of thrust on the pilot. The cockpit then continued to rotate up to 90°. With an abrupt change in axial acceleration (staging, partial loss of thrust, etc.) it rotated downward a portion of the way, but then returned to + 90° as a function of the washout. With a total loss of thrust the cockpit rotated down to the horizontal (0°) position in approximately three seconds and remained in this position.

Noise Generation - The combination of engine and aerodynamic noise was simulated by a high fidelity speaker system located in the dome surrounding the cockpit. Most of the noise contained frequencies between 50 and 2000 cps with the low frequency noise ranging from 100 to 150 cps. The maximum intensity level inside the closed cockpit near the pilot's head was 104 db. Figure 3 shows the history of noise level vs. time for the standard boost where 104 db occurred at maximum "q". Corresponding deviations were programmed as applicable for each malfunction run.

Instrumentation of Seat and Pilot - In the interest of pilot safety and to establish the vibration profile (Figure 2), instrumentation of the cockpit seat and the pilot was included during the simulator set-up and shakedown. This was done to determine the frequencies and levels of vibrational accelerations applied to the simulator seat, to determine the frequencies and levels of vibrational accelerations imposed on the pilot at various locations due to

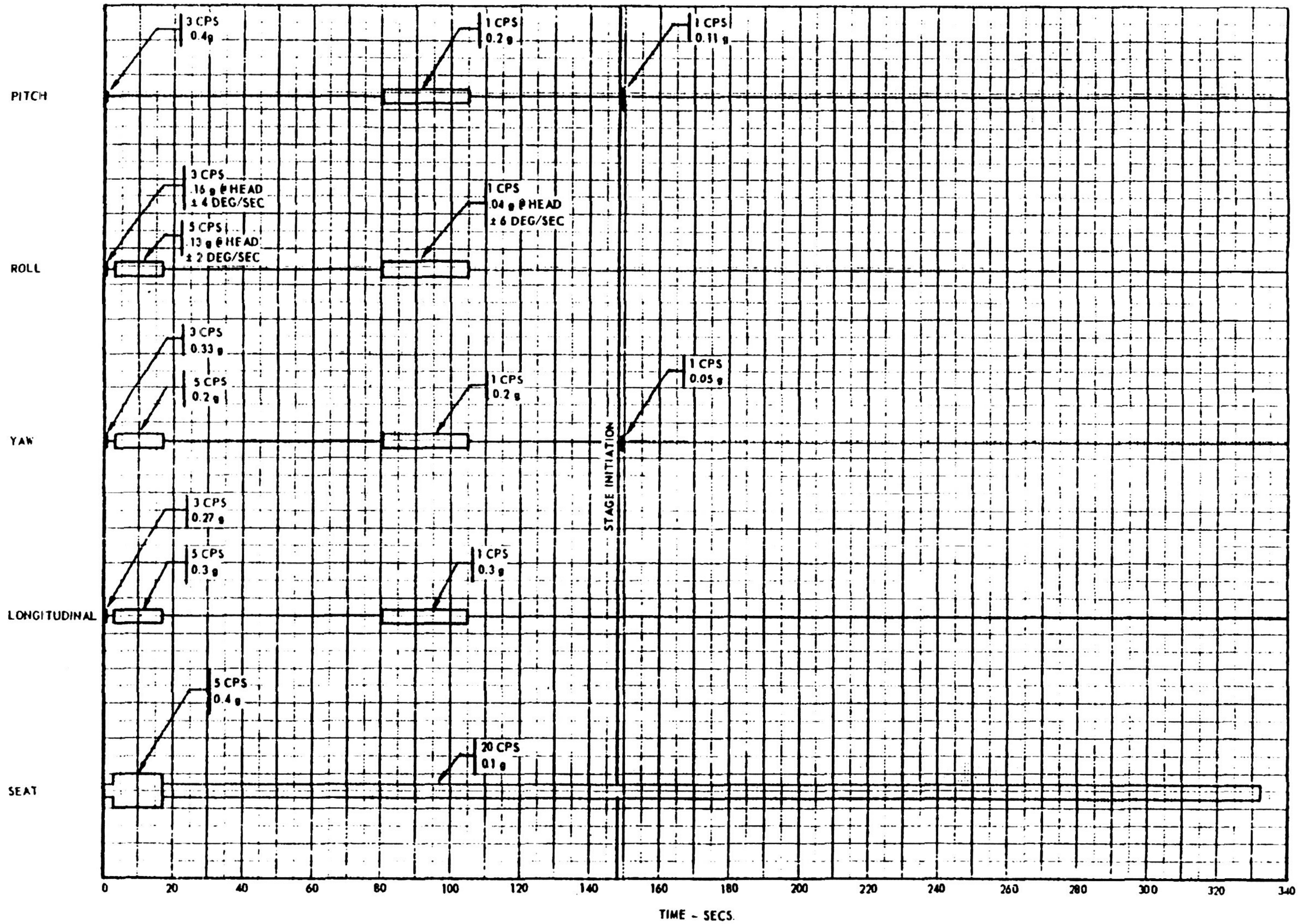


FIGURE 2 – VIBRATION PROGRAM

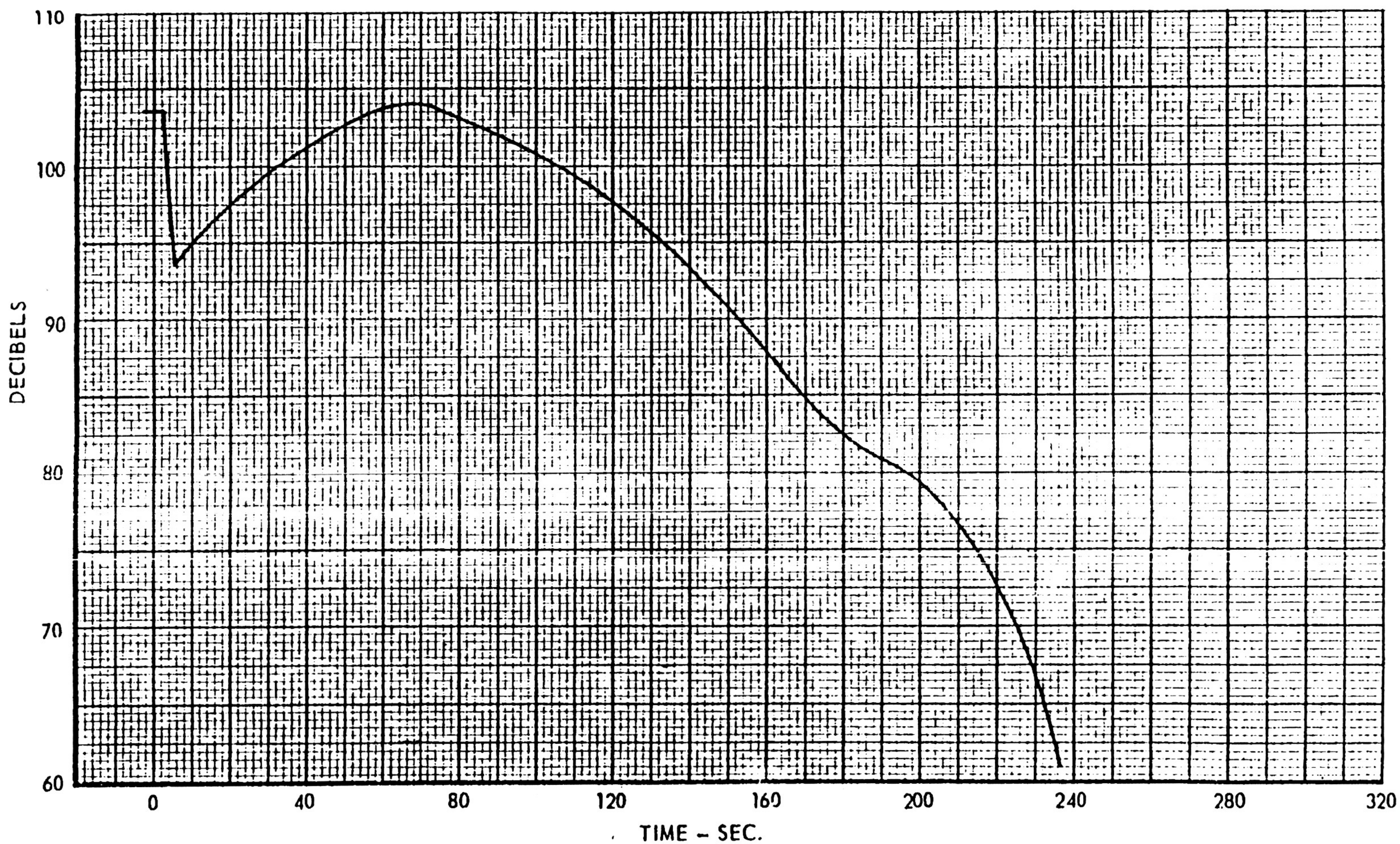


FIGURE 3 – NOISE PROGRAM

the applied forcing function, and to permit visual display of pertinent "safety of flight" data for monitoring by a qualified physician. Measurements of interest to this program were: (a) seat accelerations (vertical, lateral and longitudinal) with seat in launch position, (b) vertical and lateral accelerations imposed on the pilot's body, head, chest, and hips, and (c) the pilot's electrocardiograph (EKG) monitored between his chest and his forehead.

After establishing the vibration profile and following an analysis by two qualified physicians of the early bioinstrumentation results, it was decided to dispense with all pilot instrumentation during the experiment proper. However, seat vibrations were monitored throughout the program to ensure the profile remained fixed.

Typical vibration accelerations experienced by subjects during the initial runs, while not reported in this study, are available upon request.

Horizon-Starfield Projector - The simulator had a horizon/starfield projector driven by the computer which could be used by the pilot for visual orientation to the horizon. However, early in the experiment it became apparent the subjects' undivided attention was required on the instrument panel, thus the projector proved to be of little value to the study.

## 4.3 Programming the Standard Boost Trajectory

The data used in programming the standard boost trajectory included the vibration and noise spectrum previously discussed and information extracted from References 1, 2, and 3. The latter information is shown in the form of curves in Figures 6-1, 6-2, 6-3, 6-4, 10-1, and 10-2 of Appendix A. These curves were generated by the digital computer to drive the cockpit instruments as a function of time. Yaw and yaw rates were zero for the normal trajectory. However, signals driving the pitch, roll, and yaw rate indicators during malfunction deviations from the normal profile (i.e., angular rates and displacements) were referenced to the vehicle body axes.

The pitch program was represented with respect to the local horizontal. The basic data was extracted from a 105 N.M. altitude direct injection into circular orbit of a Titan launched at 90° E. Limits of the axial load factor ranged from 1.3 g's at lift-off to 7.3 g's (maximum).

## 4.4 Programming the Malfunctions Runs

The following is a description of the computer-flight simulator programming of the malfunction runs. Reference should be made to Table A-1 (Appendix A) and its supporting figures for a more detailed discussion.

(1) Problem I-1, Partial Loss of Thrust - One Engine (1st Stage)

The assumption was made that a malfunction began at T + 2.0 seconds resulting in one first stage engine dropping to 65% of its maximum thrust at T +7.0 seconds. The instrument panel indication was a Chamber 1 Light at T + 7.0 seconds and a fall-off of the G meter from normal (Figure 1-1). Simultaneously, there was a reduction in noise and the moving base (cockpit) was rotated down somewhat to reduce the back-to-chest force.

(2) Problems II-1 and 2, Total Loss of Thrust - One Engine (1st Stage

In both of these malfunction runs, one beginning at T + 2.0 seconds and the other at T + 15.0 seconds, it was assumed that once the malfunction began, the engine thrust dropped to 65% of maximum in 0.3 seconds at which time the Chamber 1 Light flashed on. The accelerometer reading dropped abruptly as shown in Figure 2-1, the moving base rotated down rapidly, and the noise level was reduced by one-half.

(3) Problems III-1 and 2, Total Loss of Thrust - Both 1st Stage Engines

Two runs of this type were simulated -- one starting at T+ 4.0 seconds and the other at T + 70.0 seconds. With the onset of the malfunction, the axial acceleration and noise dropped to zero immediately. In each case the Chamber 1 Light came on at 0.3 seconds following the malfunction onset. In the latter run, attitude deviation from normal was substantial resulting in a Pitch Rate Light coming on at T + 71.0 seconds (Figure 3-1).

(4) Problems IV-2 and 3, Hardover Engine Nozzle

For both cases of the hardover engine gimble failure it was assumed a non-oscillatory attitude divergence would result. In one case the malfunction began at T + 47.0 seconds and in the other at T+ 60.0 seconds. For both cases, the respective Rate Lights came on 0.2 seconds following onset of the malfunction. Respective pitch, yaw, and roll angular displacements were programmed into the moving base in accordance with data shown in Figures 4-2 and 4-3. Axial acceleration was assumed to be normal for both cases.

(5) Problems V-1, 2, and 3, Staging Failures

In the interest of clarity, the normal operating sequence for the panel lights during staging was as follows:

| | |
|---|---|
| Chamber 1 | - off all the time |
| Chamber 2 | - on at T = 0, off at 148.7 sec. |
| Fire Bolts | - on at 148.0 sec., off at 153.0 sec. |
| No Stage | - off all the time |

Problem V-1 was concerned with a premature light-off of the second stage at T + 140.0 seconds. The theoretical analysis showed that if the second stage ignited before the bolts had blown, a catastrophe (fire ball) would occur in about 2.1 seconds. Panel indications were the Pressure 2 Light went off at T + 140.7 seconds - at which time the engine had reached 65% of its thrust; the Fire Bolts Light never came on; and the No Stage Light came on at T + 142.1 seconds.

Problem V-2 was a case of the bolts firing prematurely at T + 110.0 seconds with aerodynamic forces causing the stages to separate. Panel indications were the Fire Bolts Light came on at T + 110.0 seconds and a pitch and pitch rate divergent oscillation with the associated Rate

Warning Light. The Rate Light "blinked" the first time at T + 117.4 seconds, and went off at T +117.6 seconds and came on again (and remained on) at T + 118.4 seconds. Test subjects were instructed to observe the rate display when such a malfunction occurred and to abort when its associated rate light came on the first time.

Problem V-3 concerned the case of bolts failing to fire at normal staging, i.e., at T + 148.0 seconds. The stage two engine ignited on schedule thus the Chamber 2 Light went off at T + 148.7 seconds. The Fire Bolts Light never came on. However, the No Stage Light was set to come on at T + 150.1 seconds. The axial acceleration dropped to zero at T +148.0 seconds and remained so -- even though the second stage ignited, since the stages were still attached.

(6) Problems VI-1, 2, 3, 5, 6, 7, 8, and 11, Tank Pressure Losses (1st Stage)

There were two panel indications for each tank pressure loss malfunction to warn the pilot. The Pressure Light came on when the pressure dropped to the malfunction detection system (MDS) sensor setting (as shown in Figures 6-1, 6-2, 6-3, and 6-4), and the tank pressure instrument gage indicated a subnormal level during a pressure or fuel leak. The time at which these various malfunctions began varied from T +0.0 seconds for four runs to T +10.0, T + 20.0, T +30.0, to T + 60.0 seconds. Four the the eight runs (Problems VI-2, 5, 7, and 11) did not require an abort because the pressure level never reached the catastrophe limit although the Pressure Light came on. The remaining runs required abort action, however. In all cases the assumption was made that a tank pressure loss did not affect the respective engine thrust.

(7) Problem VIII-1, D.C. Power Failure (1st Stage)

This malfunction run assumed a D.C. power failure in the first stage, starting at T +12.0 seconds, which resulted in a loss of attitude control of the vehicle. The first cockpit indication was a D.C. Power Light at T +12.0 seconds followed by a Yaw Rate Light at T +12.50 seconds. The yaw rate display also diverged and was accompanied by a yaw acceleration motion.

(8) Problems IX-1, 2, 3, and 4, Instrument Light Failures

Instrument light failures were programmed as follows: a Chamber 1 Pressure Light at T+ 2.0 seconds; a Tank 1 Pressure Light at T +40.0 seconds; a Pitch Rate Light at T+ 60.0 seconds; and a Yaw Rate Light at T +148.0 seconds. When these failures occurred without backup information, the pilot was expected to correctly diagnose the situation and refrain from aborting the mission.

## 5.0 RESULTS AND DISCUSSION

The results obtained from this investigation are presented in Table 2. The first part of the table shows pilots' actual response times and decisions compared with the required response times. The right-hand portion of this table also contains a numerical summary of the results. A discussion of the results in this table is presented in the following pages in the form of a review of each separate problem or group of similar problems. A short summary of the pertinent factors relating to each problem is tabulated at the outset since it is important to understand all the factors entering into the decisions and response times.

Where applicable, there is a discussion of possible vehicle modifications in areas such as instrumentation presentation, abort procedures, design, etc. Accordingly, this test series is considered a step in the iterative process of arriving at final design decisions.

It is emphasized that one of the ground rules in setting up the series of test runs, was that the pilot was not to respond to a single malfunction cue, but was to verify his initial observation of the possible malfunction with a second confirming piece of information. The response time, both the required and the actual, was that from the initial onset of the malfunction to the time that the abort action was completed or should have been completed by the pilot (i.e., to the closing of the contact upon pulling the D-ring).

It should be kept in mind in reviewing the results that extensive training would, in all probability, assist in improving response times which would be of considerable value in cases where these times are marginal. While some "pretraining" was included, it is not the equivalent of the comprehensive training program that Gemini pilots will receive.

In reviewing marginal cases it should be noted that the "required response times" were the result of certain assumptions used in the theoretical analysis as shown in Appendix A, and may, in some cases, be on the conservative side. In these cases a more rigorous analysis of the abort malfunction sequence might result in a more favorable comparison. The required response times are certainly not accurate to the hundredths of a second as shown in Table 2. These numbers resulted from the subtraction of an estimated "abort sequencing time" (estimated at 0.28 seconds) from the nominal time increment derived in Appendix A.

## 5.1 Result of Individual Simulated Runs

### Problem I-1 Partial Loss of Thrust - One Engine (1st Stage)

| | Time Sec. | Cues Available |
|---|---|---|
| Malfunction begins | T + 2.0 | Gradual loss axial accel. feel<br>Gradual decrease axial accel. instr.<br>Gradual reduction in noise |
| | T + 7.0 | Chamber light comes on<br>Axial accel. reading reduced from 1.3 g to 1.1 g<br>Noise further reduced |
| Required completion of abort action | T + 11.72 | |

Required Response Time (sec.) = 9.72

Mean Pilot Response Time (sec.) = 6.88*

From Table 2 it can be seen that in all eight cases where abort was correctly elected it was accomplished within the required time.

The pilots indicated they used the light and loss of axial acceleration feel as the main cues. In five cases the pilots were generally unable to detect the initial cues in the time period T + 2.0 to T + 7.0 and hence were not responsive to the Chamber Light as the abort signal and looked for additional cues. The problem, therefore, is not one of reaction response time (all who elected to abort made it satisfactorily), but one of obtaining confirmation that the Chamber Pressure Light was correct.

It is noted that 4.72 seconds was available from the Chamber Light to abort action. It has been determined in discussion with NASA personnel that this time would permit verification of loss of thrust by the control center and confirmation to the pilot.

* Mean R.T. for those runs where pilot aborted.

Problem II-1 Total Loss of Thrust - One Engine (1st Stage)

| | Time Sec. | Cues Available |
|---|---|---|
| Malfunction begins | T + 2.0 | Rapid loss axial accel. feel<br>Rapid decrease axial accel. instr. |
| | T + 2.3 | Chamber light comes on<br>Axial accel. reading reduced from 1.3 g to 0.65 g<br>Significant reduction in noise |
| Required completion of abort action | T + 6.02 | |

Required Response Time (sec.) = 4.02

Mean Pilot Response Time (sec.) = 1.86

All pilots accomplished this test satisfactorily. Pilots indicated they were responsive to the light, acceleration feel and a greater response to the sound cue than in I-1. This test points up the discussion above for I-1 since, while the required response time was significantly less, all aborts were within the required time due mainly to the sharper definition of confirming cues. This sharper definition resulted from total loss of thrust of one engine compared to gradual loss of thrust in I-1.

Problem II-2 Total Loss Thrust - One Engine (1st Stage)

| | Time Sec. | Cues Available |
|---|---|---|
| Malfunction begins | T+ 15.0 | Rapid loss axial accel. feel<br>Rapid decrease axial accel. instr. |
| | T + 15.3 | Chamber light comes on<br>Axial accel. reading reduced from 1.4 g to 0.7 g<br>Significant reduction in noise |
| Required completion of abort action | T + 32.02 | |

Required Response Time (sec.) = 17.02

Mean Pilot Response Time (sec.) = 1.03

This problem is similar to II-1 except it occurs at T + 15 sec. instead of T + 2 sec. The greater altitude gives more room for a longer response time. With the adequate cues available, all pilots made aborts satisfactorily. The mean response times were actually lower than for II-1 perhaps due to being in a portion of the boost where no other motions existed and the motion cues produced by the malfunction were more easily identified.

## Problem III-1 Total Loss Thrust - Both Engines (1st Stage)

| | Time Sec. | Cues Available |
|---|---|---|
| Malfunction begins | T + 4.0 | Abrupt loss axial accel. feel<br>Abrupt decrease axial accel. instr. |
| | T + 4.3 | Chamber light comes on<br>Axial acceleration reading reduced from 1.3 g to 0<br>Complete reduction in noise |
| Required completion of abort action | T + 5.22 | |

Required Response Time (sec.) = 1.22

Mean Pilot Response Time (Sec. = 0.85

Similar to II-1 except that loss of both engines rather than one provides even more marked cues. Pilots experienced no difficulty in performing this test within required times.

## Problem III-2 Total Loss Thrust - Both Engines (1st Stage)

| | Time Sec. | Cues Available |
|---|---|---|
| Malfunction begins | T + 70.0 | Abrupt loss axial accel. feel<br>Abrupt decrease axial accel. instr.<br>Pitch rate divergence starts |
| | T + 70.3 | Chamber light comes on<br>Axial accel. reading reduced from 2.0 g to 0<br>Complete reduction in noise |
| | T + 71.0 | Pitch rate light comes on |
| Required completion of abort action | T + 71.62 | |

Required Response Time (sec.) = 1.62

Mean Pilot Response Time (sec.) = 0.89

This run was similar to III-1 except it occurred later in boost (T + 70). Again well defined cues permitted all pilots to complete abort in time. More use of noise cues than in III-1 was reported by pilots. Because of high flight dynamic pressure, pitch rate divergence was encountered in this case. However, rate cue was not mentioned by the pilots and the rate warning light came late compared to other cues and was probably not used. Mean response times for both III-1 and III-2 were less than those for I-1, II-1, and II-2 due to very sharp loss of thrust acceleration and noise.

Problem IV-2 Hardover Engine Gimbal (1st Stage)
(Divergence in Yaw)

| | Time Sec. | Cues Available |
|---|---|---|
| Malfunction begins | T + 47.0 | Divergent yaw rate inst.<br>Yawing acceleration feel |
| | T + 47.2 | Yaw rate light comes on<br>Divergent yaw angle instr.<br>Yawing acceleration feel<br>Divergent yaw rate inst. |
| Required completion of abort action | T + 48.02 | |

Required Response Time (sec.) = 1.02

Mean Pilot Response Time (sec.) = 1.33

Problem IV-3 Hardover Engine Gimbal (1st Stage)
(Divergence in Pitch)

| | Time Sec. | Cues Available |
|---|---|---|
| Malfunction begins | T+ 60.0 | Divergent pitch rate instr.<br>Pitching acceleration feel |
| | T + 60.2 | Pitch rate light comes on<br>Divergent pitch angle instr.<br>Pitching acceleration feel<br>Divergent pitch rate instr. |
| Required completion of abort action | T+ 60.62 | |

Required Response Time (sec.) = 0.62

Mean Pilot Response Time (sec.) = 1.26*

Both of these cases are similar and can be discussed together. Table 2 shows that while the correct decision was made in all but one of the 27 runs simulated, only one abort was made within the required time. It was recognized when the experiment was set up that the short required response times could probably not be met. This is especially so in view of the mean basic response times of 0.42 sec. discussed in Section 3.

Despite the required short response times, the pilots reported that they were responsive to the rate instruments and the angular acceleration feel in addition to the rate limit lights.

* Mean R.T. for those runs where pilot aborted

During the preparation of the experiment it was learned that the engine manufacturer expects to reconfigure the nozzle control system so that hardover engine malfunctions will have a negligible probability of occurrence. However, it was agreed with NASA that such failures would be included in the experiment in order that data would be obtained on what the pilot could do. Note that the mean response time of the subjects who elected abort is only of the order of 0.6 sec. longer than the required time. Should the revision in the control system to prevent hardover gimbal malfunctions prove unsatisfactory, the pilot response times in Table 2 should be of assistance in analyses to determine the degree of potential hazard.

Problem V-1 Staging - Premature Light Off of 2nd Stage

| | Time Sec. | Cues Available |
|---|---|---|
| Malfunction begins | T +140.0 | None |
| | T + 140.7 | Pressure Chamber Light 2 goes off (before scheduled T + 148.7) |
| | T + 142.1 | No Stage Light comes on |
| Required completion of abort action | T + 142.42 | |

Required Response Time (sec.) = 2.42

Mean Pilot Response Time (sec.) = 2.97

Table 2 shows that, while all pilots made correct decision, only four of eleven runs were within the required response time. The primary problem was the lack of an adequately timed secondary cue to verify the Chamber Light "off" signal. In this circumstance there was no change in acceleration, the increase in engine noise was probably not discernable, and the pilot had nothing to confirm the correctness of the Chamber Pressure Light. A solution would be to provide a second indication such as a fire-in-the-hole sensor and display system. It is suggested that the use of fiber optics (light pipes) be investigated as a possible source of hardware for such a display device to provide immediate malfunction confirmation.

Some form of interlock is also a possible solution, but there is reason to question whether a fire-in-the-hole is actually catastrophic. It is understood that one case has already occurred in which the 2nd stage burned away from the first stage and successfully continued the mission.

There is little reason to doubt that the scores on these 11 trials would all have been positive, had a fire-in-the-hole display been available.

Problem V-2 Staging - Bolts Fire Prematurely

| | Time Sec. | Cues Available |
|---|---|---|
| Malfunction starts | T + 110 | Fire bolt light comes on (before scheduled T + 148) Oscillation - pitch rate instr. |
| | T + 117.4<br>T + 117.6<br>T + 118.4 | Pitch rate light on<br>Pitch rate light off<br>Pitch rate light on<br>Oscillation - pitch rate instr. |
| Required completion of abort action | T + 118.72 | |

Required Response Time (sec.) = 8.72

Mean Pilot Response Time (sec.) = 7.55

The reference documents state that an abort is not necessarily required if the bolts fire prematurely. The case used in the experiment assumed that a divergent pitch oscillation occurred requiring an abort.

Table 2 shows that two of the test subjects aborted without waiting to see if an abort would be required*. If this procedure were to be followed in practice, there would be no problem aborting in time, but an unnecessary abort could result. The other subjects waited for the pitch oscillation to diverge to limit pitch rate before aborting. One subject responded to the first wink of the rate warning light and aborted successfully, but the others waited for the second flash and lost one second of the available time. It is felt that after more training the pilots could be expected to abort satisfactorily.

Another consideration in this case is that an arbitrary rate of divergence on the oscillation was assumed. An analysis should be made to determine what effects can actually be anticipated and then use a pilot response time of one second to determine if catastrophe would occur. The experiment showed that the subjects were able to execute abort in 0.8 to 1.0 second after obtaining the decisive display information.

*Note: These early aborts resulted in the unrealistic mean pilot response time as shown.

Problem V-3 Staging - Bolts Fail to Fire

| | Time Sec. | Cues Available |
|---|---|---|
| Malfunction begins | T + 148.0 | 1st stage axial acceleration feel drops to 0<br>Fire Bolts light does not come on (as normally expected) |
| | T + 148.7 | Chamber 2 Light goes off<br>No axial accel. feel - |
| | T + 150.1 | No Stage Light comes on |
| Required completion of abort action | T + 150.42 | |

Required Response Time (Sec.) = 2.42

Mean Pilot Response Time (Sec.) = 1.92

Since there was 2.42 seconds response time available it was deemed advisable for the pilot to delay the abort as long as he could to allow the bolts to fire in the event of a momentary hang fire. Thus, a No Stage timer light was put on the panel and set for 2.1 seconds after fire bolts signal was initiated. This allowed the pilot only 0.32 seconds to respond after the No Stage Light came on.

Table 2 shows that 16 of the 22 trials were accomplished satisfactorily. In these cases the pilots did not wait for the No Stage Light. The six trials in which the pilots waited resulted in late aborts. The delay caused by the No Stage Light is not advisable and the light should be eliminated.

The preferred approach to this problem is to provide a manual override for firing the bolts if the automatic system fails.

The same discussion as in V-1 applies here relative to the real hazard of "fire-in-the-hole" and the desirability of a warning signal for this situation.

Had all pilots responded to Chamber 2 Light going off with Fire Bolts Light being off, or if a definite fire-in-the-hole signal had been available in addition, all pilots could have made this run satisfactorily.

Problem VI - Tank Pressure Loss (Stage 1 - Oxidizer)

| Problem | Malfunction Start Sec. | Tank Light On Sec. | Req'd Completion of Abort Action Sec. | Req'd. R.T. Sec. | Mean Pilot R.T. Sec. |
|---|---|---|---|---|---|
| VI-1 | T + 0 | T + 2.0 | T + 3.22 | 3.22 | 2.73 |
| VI-2 | T + 0 | T + 10.5 | -------- | NAR* | |
| VI-6 | T +10 | T + 12.3 | T + 14.72 | 4.72 | 3.65 |
| VI-7 | T + 20 | T + 24.5 | -------- | NAR* | |
| VI-8 | T +30 | T + 31.4 | T+ 36.12 | 6.12 | 4.46 |

*NAR - No abort required

The above cases of oxidizer tank pressure losses are considered as a group. Figure 6-2 of Appendix A should be consulted to review the pressure rate variations.. Problems VI-2 and VI-7 are more slowly varying and level off above the limit pressure shown in Figure 6-2 and therefore do not require abort. In the other three cases the pressure losses are more rapid and all require abort. The pressure loss is sufficient in all cases that the MDS warning signal comes on. The pilot was required to compare rate of the normal pressure decrease and rapidity of approach to limit pressure. The MDS light was an additional one.

Table 2 shows that the NAR problems were correctly interpreted in 9 out of 10 cases. In those runs (35) requiring abort 28 were in time, 6 not in time, and one no abort. Of those not in time the errors were quite small -- the greatest being 0.054 sec. Generally, the errors made in these latter cases were not caused by failure to observe the malfunction or by not reacting quickly enough, but rather by indecision as to whether or not the pressure loss would really require abort.

It was the opinion of the pilots that since the limit pressure in Stage 1 oxidizer tanks is a linear and symmetrical function of time (from 0 to 2 psi and back to 0) adequate training would enable making proper and timely decisions in all cases.

Problem VI - Tank Pressure Loss (Stage 1 - Fuel)

| Problem | Malfunction Start Sec. | Tank Light On Sec. | Req'd Completion of Abort Action Sec. | Req'd. R.T. Sec. | Mean Pilot R.T. Sec. |
|---|---|---|---|---|---|
| VI-3 | T + 0 | T + 4.0 | T + 6.72 | 6.72 | 4.97 |
| VI-5 | T + 0 | T + 20.0 (on)<br>T + 29.0 (off) | --------- | NAR* | |
| VI-11 | T + 60 | T + 108.5 | --------- | NAR* | |

Figure 6-1 of Appendix A further illustrates these cases of fuel tank pressure loss showing the rate at which pressure falls. VI-5 is a slowly varying loss which just dips below the MDS warning signal and then levels off just above the MDS setting requiring no abort. VI-11 is also a slowly varying pressure loss that does not reach the limit pressure and hence no abort is necessary. VI-3 is a rapid loss that requires abort.

Table 2 shows that all runs of VI-3 were performed within required time except one which was only 0.02 sec. late. All the no abort runs were performed satisfactorily.

It is important to note that there were 23 runs in VI-2, 5, 7, and 11 in which the MDS as an automatic abort signal would have caused unnecessary aborts while the pilots correctly decided not to abort 22 times.

Problem VIII-1 D.C. Power Failure (1st Stage)

| Malfunction Begins | Time Sec. | Cues Available |
|---|---|---|
| Malfunction begins | T + 12.0 | D.C. Power Light comes on<br>Divergent yaw rate instr.<br>Yawing accel. feel |
| | T + 12.50 | Yaw Rate Light comes on<br>Divergent yaw angle instr.<br>Yawing accel. feel<br>Divergent yaw rate instr. |
| Req'd completion of abort action | T + 14.72 | |

Required Response Time (Sec.) = 2.72

Mean Pilot Response Time (Sec.) = 2.19

The results of Table 2 show that in 5 out of the 7 runs this situation was handled satisfactorily. One of the misses was only 0.01 sec. late; the other was 73% slower than the slowest of the other pilots. What caused the one pilot to be 1.26 sec. late aborting is not known, but it is believed that with adequate training all pilots could abort in time.

Problem IX - Warning Light Failures

| Problem | Warning Light Malfunction | Malfunction Starts Sec. | Cues Available |
|---|---|---|---|
| IX-1 | Chamber 1 Pressure | T + 2.0 | No decrease in noise, axial accel. feel, or axial accel. instr. |
| IX-2 | Tank 1 Pressure | T + 40.0 | Tank pressure increasing (in normal boost fashion) |
| IX-3 | Pitch Rate | T + 60.0 | No instr. indication of pitch rate of angle<br>No pitching accel. feel |
| IX-4 | Yaw Rate | T + 148.0 | No instr. indication of yaw rate of angle<br>No yawing accel. feel* |

*However there was a mild oscillation at T + 149.0 (1 cps at 0.05 g) continuing for one second which occurred during normal staging.

All of these were problems representing erroneous warning light indications in which no abort was required. In most cases there were cues available to confirm that the light was malfunctioning. Table 2 shows that for cases (such as IX-2) where the confirming cue was contrastingly clear (pressure increasing when light would indicate decreasing) correct decisions were made in all cases. In other cases a number of incorrect decisions were made. It is believed that some of the incorrect decisions relating to the IX-4 were caused by the programmed mild oscillation representing a disturbance caused by stage separation.

The pilots generally felt that more experience (training) with this particular type of malfunction would permit them to handle these situations satisfactorily.

## 5.2 Abort Mode Selection Response

While not recorded in Table 2 the results of the abort mode selection task should be reported. As pointed out in "Experimental Procedures" (Section 3.0), all pilots were instructed to change from seat ejection to capsule abort mode at Approximately T + 100 secs. by flipping the mode switch on the instrument panel. They were given no additional instructions on this during the boost and were expected to accomplish this task along with their duties of monitoring for possible boost malfunctions. It is considered significant that in the 73 runs that extended beyond the T + 100 second limit, all pilots responded to this task correctly.

## 5.3 Automatic vs. Manual Abort

The scope of this study was to obtain a qualitative evaluation of manual abort reliability. An analysis of the automatic abort system reliability for direct comparison was beyond the scope of the study. However, some of the cases of Oxidizer and Fuel Tank Pressure Loss are examples of an inadequate automatic abort sensing system, even when the system is functioning correctly. It is believed that a thorough analysis including both reliability for aborting when required and not aborting when not required will show the overall hazard to be greater with an automatic abort system than with a manual abort system.

## 5.4 Proposed Abort Monitoring Panel Displays

Figure 4 shows an instrument panel designed to incorporate the conclusions of this experiment. It is intended to show the simplest grouping of display parameters required for monitoring abort contingencies. All of the parameters which had any value in detecting, interpreting, and deciding the need for abort during the experiment are included. Those parameters used in the experiment, but which had no real bearing on the abort monitoring task, have been eliminated.

The fuel and oxidizer pressure gages are time shared between the first and second stages*. After T + 140 seconds the first stage tanks do not require monitoring. Switching to second stage tanks at T + 140 seconds leaves 8 seconds prior to light-off of second stage engines and allows sufficient time for aborting prior to staging in the event second stage tanks are below limit pressure. The "bugs" shown on these pressure gages are used to show second stage tank catastrophe limits. This assumes that these limits are large values and variable with time. The "bugs" are driven by clock-cam mechanisms.

Each segment of the two dial gages contain red edge lighting for advisory warning that the particular parameter is abnormal.

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*Information received subsequent to the experiment indicates that both first and second stage tanks must be monitored durirg first stage operation. Therefore time sharing is not possible and two gages are required.

The Chamber 1 and Chamber 2 lights (red) are to indicate when chamber pressure is below 65% of normal. The Fire Bolts light (green) indicates that the staging bolts have blown. The Fire-in-the-Hole-light (red) is the display for a secondary, heat sensing system to confirm the Chamber 2 light in the event of a fire-in-the-hole. The D.C. power light (red) indicates when D.C. power is below limit.

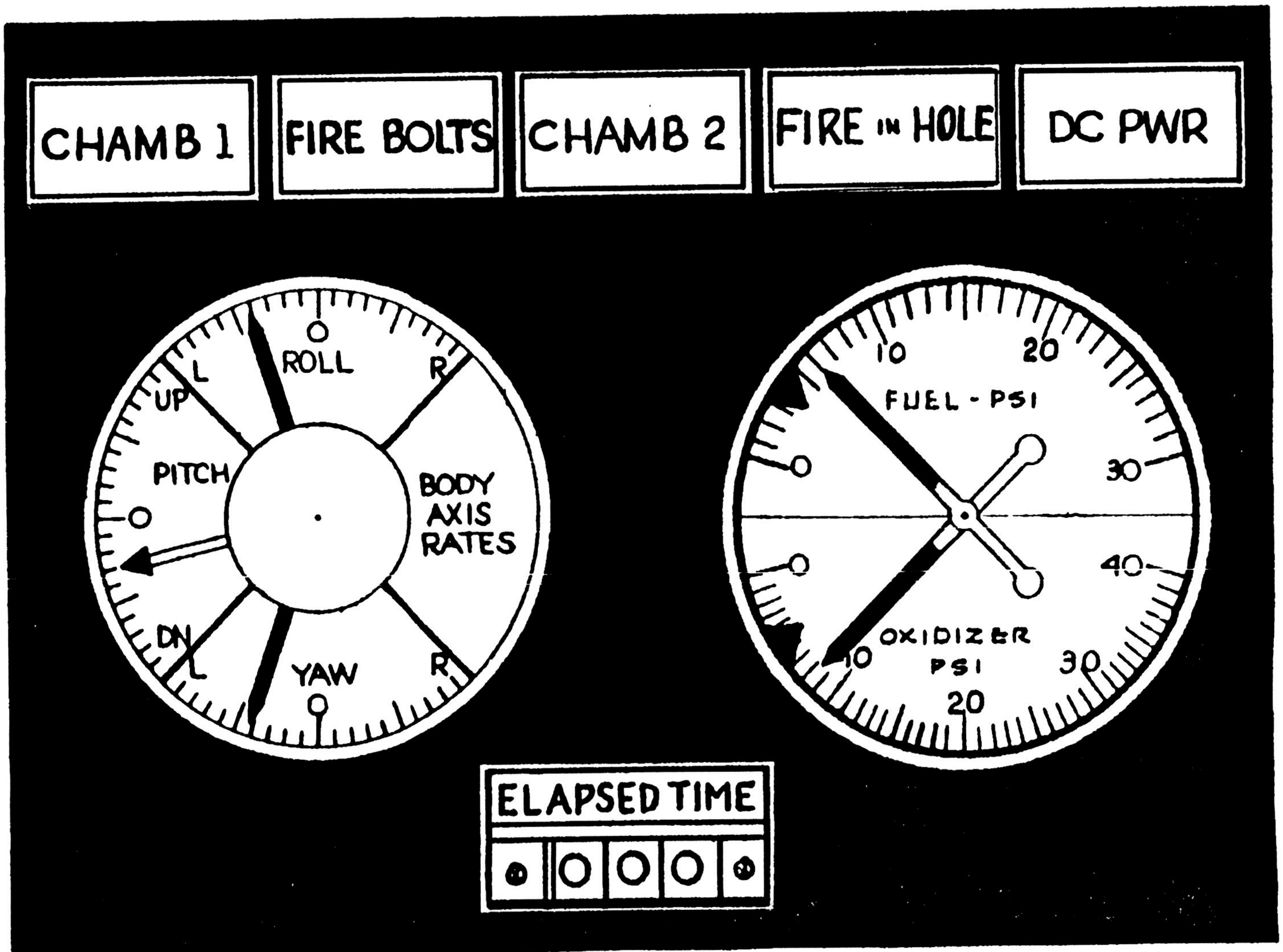


FIGURE 4 – PROPOSED ABORT MONITORING PANEL

## 6.0 CONCLUSIONS

From this study it is concluded that:

(1) Pilot monitoring of the boost systems with manual abort capability is a logical extension of aircraft piloting and escape procedures.

(2) Critical booster malfunctions were readily apparent through multiple cues such as linear or angular acceleration, noise, and cockpit displays.

(3) Tank pressure and body axis rate gages provide vital analog trend information.

(4) With adequate cue(s), manual abort is possible within one second of the onset of a malfunction.

## TABLE 2 – RESPONSE TIME SUMMARY

| PROBLEM NO. | | ACTUAL RESPONSE TIMES BY PILOT -- Secs. A | B | C | D | E | F | REQUIRED RESPONSE TIME (Secs.) | MEAN RESPONSE TIME (Secs.) | NUMBER CORRECT DECISIONS In Time | No Time Req'd. | Not In Time | NUMBER INCORRECT DECISIONS | TOTAL NUMBER RUNS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I-1 | Thrust 1 Engine | 8.97 D 5.52 | 5.78 5.68 | D D | D 6.20 | D 7.92 | 6.93 8.03 | 9.72 | 6.88* | 8 | | | 5 | 13 |
| II-1 | Thrust 1 Engine | 2.82 2.71 | 1.03 .98 | 2.12 1.24 | 3.22 2.80 | .98 2.80 | .82 .82 | 4.02 | 1.86 | 12 | | | | 12 |
| II-2 | Thrust 1 Engine | .98 | .72 | 1.29 1.24 | 1.24 | .93 | .87 | 17.02 | 1.03 | 7 | | | | 7 |
| III-1 | Thrust 2 Engines | .91 .75 | .80 .96 | .80 .70 .75 .75 | .75 1.06 | .75 1.17 | .80 .96 | 1.22 | 0.85 | 14 | | | | 14 |
| III-2 | Thrust 2 Engines | .76 .70 | .87 1.13 | .71 1.02 | .71 .71 | 1.02 .92 | 1.28 .87 | 1.62 | 0.89 | 12 | | | | 12 |
| IV-2 | Engine Gimbal | 1.10 1.04 1.20 | 1.46 .94 | 1.31 1.51 | 1.20 | 1.51 1.83 | 1.67 1.15 | 1.02 | 1.33 | 1 | | 11 | | 12 |
| IV-3 | Engine Gimbal | D 1.41 | 1.26 .89 .73 | 2.41 1.20 | 1.41 .94 .79 | 1.67 1.66 | 1.52 .89 .79 | 0.62 | 1.26* | | | 14 | 1 | 15 |
| V-1 | Staging | 2.78 | 3.20 1.47 | 3.25 2.78 | 2.36 2.00 | 2.41 2.47 | 7.22 2.73 | 2.42 | 2.97 | 4 | | 7 | | 11 |
| V-2 | Staging | 11.47 9.33 | 3.01 | 8.39 | 2.12 | 9.23 | 9.28 | 8.72 | 7.55 | 3 | | 4 | | 7 |
| V-3 | Staging | 2.77 1.25 | 1.46 1.15 .99 1.10 | 2.04 1.83 1.62 1.36 1.41 | 3.40 2.93 2.61 1.93 | 2.51 2.04 1.78 1.62 | 3.29 1.52 1.62 | 2.42 | 1.92 | 16 | | 6 | | 22 |
| VI-1 | Tank Pressures | 2.61 3.03 | 3.39 2.45 | 1.93 3.65 2.40 | 2.61 3.34 | 2.19 2.61 | 2.98 2.40 2.66 | 3.22 | 2.73 | 11 | | 3 | | 14 |
| VI-2 | Tank Pressures | + | + | (No Test) | + | + | + | NAR | ---- | | 5 | | | 5 |
| VI-3 | Tank Pressures | 4.54 4.49 | 5.12 | 4.49 | 6.74 | 4.59 | 4.86 | 6.72 | 4.97 | 6 | | 1 | | 7 |
| VI-5 | Tank Pressures | + | + | + | + | + | + | NAR | ---- | | 6 | | | 6 |
| VI-6 | Tank Pressures | 2.79 3.00 | 2.79 4.20 | 4.46 3.05 4.05 | 4.93 3.21 | 2.95 4.15 | 4.26 | 4.72 | 3.65 | 11 | | 1 | | 12 |
| VI-7 | Tank Pressures | + | + | (No Test) | D | + | + | NAR | ---- | | 4 | | 1 | 5 |
| VI-8 | Tank Pressures | 6.66 1.80 3.16 | 6.29 | 4.68 D | 3.32 | 5.61 | 4.15 | 6.12 | 4.46 | 6 | | 2 | 1 | 9 |
| VI-11 | Tank Pressures | + | + | + + | + | + | + | NAR | | | 7 | | | 7 |
| VIII-1 | D.C. PWR | 1.42 | 2.31 | 3.98 2.73 | 1.47 | 1.63 | 1.79 | 2.72 | 2.19 | 5 | | 2 | | 7 |
| IX-1 | Warning Lights | + | D | D | D | + | + | NAR | ---- | | 3 | | 3 | 6 |
| IX-2 | Warning Lights | + | + | + + + | + | + | + | NAR | ---- | | 8 | | | 8 |
| IX-3 | Warning Lights | + | + | (No Test) | D | D | D | NAR | ---- | | 2 | | 3 | 5 |
| IX-4 | Warning Lights | D | D | D | D | + | + | NAR | ---- | | 2 | | 4 | 6 |
| Normal Boosts | | +++++ | ++++ | D++++ | ++++ | ++++ | ++++ | NAR | ---- | | 26 | | 1 | 27 |
| | | | | | | | | | | 116 | 63 | 51 | 19 | 249 |
| | | | | | | | | | | $\underbrace{116 + 63}_{179}$ | | | | |
| | | | | | | | | | | $\underbrace{179 + 51}_{230}$ | | | | |

**Legend:**

+ No Abort (Correct -- "No Abort" Runs)

D Decision Incorrect (Aborted on "No Abort" or failed to abort on required abort runs)

NAR No Abort Required

*Note: Mean R.T. for those runs where pilot aborted.

## REFERENCES


| | |
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# APPENDIX A

## GEMINI BOOST ABORT STUDY

Theoretical Analysis of Abort Situations - Titan II

1. Booster Failures - General

To facilitate the analysis of the abort situations during the boost phase, a study was initially made of booster rocket failures. The prime source for this information was a Vought Document AST/EIR-13441, which presents the number of successes and failures of the various rocket firings from Cape Canaveral and elsewhere. Of those firings which resulted in failure, the suspected cause of the failure was tabulated. These data were accumulated from 202 firings dating from 9-24-58 to 8-9-60. It was determined that the booster failures were distributed, in general, in the following pattern:

| | |
|---|---|
| Launch (first 10 sec.) | 19.5% |
| High "q" region | 7.9 |
| Thrust termination and separation | 33.3 |
| 2nd stage malfunctions | 39.3 |
| | 100.0% |

Another distribution of the failures was made according to the type of malunfction which occurred and is presented below:

| | |
|---|---|
| Partial loss of engine thrust | 2.8% |
| Complete thrust termination | 30.5 |
| Hardover engine | 2.8 |
| Tank pressurization loss | 25.0 |
| Attitude control | 30.5 |
| Staging | 8.4 |
| | 100.0% |

2. Titan II Malfunction

With this background information, the documents referenced in the report pertaining to the Titan II booster system were studied for various abort possibilities. The probabilities of various malfunctions were tabulated as follows: (Reference 2)

| | Stage I | Stage II | Total |
|---|---|---|---|
| Tank collapse | .013046 | | .013046 |
| Hardware thrust vector | .004608 | .002450 | .007058 |
| No. sep. bolt release | .003622 | | .003622 |
| Thrust termination | .003096 | .005814 | .008910 |
| Engine I fail to stop | .000386 | | .000386 |
| Early sep. bolt release | .000007 | | .000007 |
| Early staging initiation | .001851 | | .001851 |
| No staging initiation | .000267 | | .000267 |

As a result of these studies, the following types of malfunctions were analyzed in detail as a source of data on which to base a selected number of experimental runs (see text):

| | | |
|---|---|---|
| I. | Partial loss of thrust of one engine | 3 cases |
| II. | Total loss of thrust of one engine | 3 cases |
| III. | Total loss of thrust of both engines | 4 cases |
| IV. | Hardover engine gimble | 3 cases |
| V. | Staging failures | 3 cases |
| VI. | Tank pressure loss | 12 cases |
| VII. | Counter-clockwise roll | 2 cases |
| VIII. | D.C. power failure | 3 cases |
| IX. | Instrument light failures | 4 cases |
| | Total Number of Situations | 37 cases |

A comprehensive breakdown of these 37 failures divided into their 9 different classifications is presented in the Master List of Abort Situations (Table A-1).

Some runs did not involve any emergency condition; some had conditions which, because of their indicated nature or the time at which they occurred, did not require an abort. All times shown in the table, with the exception of the "Required Response Times" -- which are shown from the moment of onset of the malfunction, are from time zero. Onsets of the appropriate warning lights are shown, and where appropriate, quantitative displays are keyed to an abnormal time-history plot of the failure. The column entitled "Time Malfunctions Begins" gives the time (actual or estimated) when failure occurred. The time at which a qualitative (warning light) indication of the failure was displayed is indicated in the appropriate column under "Lights". The "Abort By" column is the time at which catastrophe (i.e., fire ball) or breakup of the vehicle would occur; the pilot must have separated from the vehicle by this time. Thus, the time shown in the "Required Response Time" column was determined as follows:

$$RT_{Reqd.} = T_{Catastrophe} - \text{Time Malfunction Begins} -$$

$$T_{RT\ of\ escape\ system*}$$

Some of the situations do not require a short response time. These are denoted N.D.R.T. or "No Definite Response Time" since the pilot could abort at "leisure".

3. Examples of Typical Abort Situations

Some typical examples of abort situations, showing the manner in which they were analyzed, are presented as follows (see Table A-1 and supporting figures)"

Example (1): Problem III-1, Total Loss of Thrust at T +4.0

Analysis of Problem: At T+ 4.0 a malfunction occurs which causes both boost engines to shut down. The chamber pressure drops to its 65% level in 0.3 sec. which causes the Chamber Pressure Light to come on at T + 4.3 (Figures 3-2). At the same time the subject should experience a cessation of G-loading. This provides a secondary indication of thrust

*In this study the RT of the escape system is assumed to be 0.28 sec.

termination. Unless abort is executed before T +5.5 secs. the pilot will hit the ground with the chute closed. The difference between T+ 5.5 and the first indication of malfunction(Chamber Pressure Light at T+ 4.3) is 1.2 seconds. Subtracting from this time delay that time interval from the initiation of abort to actual escape separation (0.28 sec.), the pilot has 0.92 seconds to respond to the light and pull the D-ring, or he must have completed his response within 1.22 seconds from the time of malfunction onset.

Example (3): Problem V-1, Early Stage II Ignition at T + 140

The Stage II Chamber Pressure Light goes off at T + 140.7 indicating that the Stage II engine has ignited and has reached 65% of thrust. There is no abnormal acceleration since the two sections remain connected. The No-Stage Light indicating this fact comes on at T + 142.1 (1.4 sec. later). Abort separation must be complete by T + 142.7 since at this time it is assumed the Stage II blast has burned through the Stage I heat shield and has caused an explosion in the Stage I tanks. The subject has 0.32 sec. to respond to the No-Stage Light or 2.42 sec. to complete his response from the instant of malfunction onset.

Example (4): Problem V-2, Staging Bolts Blow Early at T + 110

In this case the Fire Bolts Light comes on at T+ 110. An immediate abort may not be necessary unless a divergent vehicle attitude is encountered. In this problem the vehicle is given a divergent pitch oscillation (Figure 5-1) which exceeds the 4 deg/sec. rate threshold (Pitch Rate Light) at T+ 117.4. It then immediately falls below the threshold at T+ 117.6 and again exceeds it at T + 118.4. This is due to the fact that the booster is oscillating. The vehicle will disintegrate at T+ 119.0, therefore the subject has a total of 8.72 sec. to respond after the Fire Bolts Light comes on, or 1.32 sec. after the Pitch Rate Light Comes on for the first time.

Example (5): Problem V-3, Staging Bolts Fail to Blow at Staging (T+ 148)

This time the Fire Bolts Light does not come on at T+ 148, i.e., when lst stage thrust terminates. The Stage II goes ahead and ignites, which presents the problem. This fact is indicated by the normal operation of the Stage II Chamber Pressure Light going off at T+ 148.7. The No-Stage Light comes on 1.4 sec. later at T + 150.1 which is the indication for the subject to immediately pull up the D-ring. The subject has 1.72 seconds to respond after the Chamber Pressure Light goes off or 2.42 seconds after the time the malfunction begins.

Example (6): Problem VI-2, Tank Pressure Loss

A malfunction occurs at T+ 0 which causes the oxidizer pressure to slowly drop below normal (Figure 6-2). The Tank Pressure Light comes on at T+ 10.5. In this problem the pressure never becomes sufficiently low to cause tank collapse, hence no abort is required (NAR).

Example (7): Problem VI-6, Tank Pressure Loss

A malfunction occurs at T + 10 which causes a rather rapid fall off of oxidizer pressure. The Tank Pressure Light will come on at T+12.3. The pressure reaches a point which causes tank collapse and explosion at T +15.0. The subject has 2.42 seconds to react to the light or he has a total response time from malfunction onset of 4.72 seconds.

It must be pointed out that in both examples 6 and 7 the Oxidizer Tank Pressure Light comes on at about the same time (10.5 and 12.3 seconds, respectively). The subject has no direct way of knowing when the malfunction occurred. Hence, the only way he can differentiate between the two (one requires abort and the other no abort) is to monitor the rate at which the pressure is falling below normal and discriminate between the rapid rate of an impending abort situation and the slower rate of problem 6. Further studies should be made in this area to determine an adequate means for the pilot to discriminate between the abort and no abort pressure losses.

Example (8): Problem VIII, D.C. Power Failure

It was assumed that if the D.C. power source fails to give the proper voltage, a warning light will be energized. It was further assumed that one of the most immediate effects of this malfunction was a loss in attitude control of the vehicle (i.e., engine position control). In this case the D.C. power warning light is followed by a divergence of the attitude and attitude rates from normal. In one case (Figure 8-1) the attitude rate is sufficiently rapid to exceed the rate threshold and gives a warning light.

Problem area IX is concerned with light malfunctions; i.e., the light comes on when no malfunction has occurred. This required the subject to monitor secondary sources of information before making an abort decision. One of the major objectives of the study was to identify those cases in which the subject would not have sufficient time to perform this information processing judgemental task.

It is believed the above limited examples of problems taken from Table A-1 will be sufficient to acquaint the reader with the method and approach taken in analyzing the many possible booster malfunctions.

TABLE A-1 MASTER LIST OF ABORT SITUATIONS

| | Problem | | Time Malfunction Begins | Abort By | Required Response Time++ | Lights $\dot{\theta}$ | Lights $\dot{\phi}$ | Lights $\dot{\psi}$ | Lights Chamber Press No. 1 | Lights Chamber Press No. 2 | Lights Tank Press No. 1 | Lights Tank Press No. 2 | Lights Fire Bolts | Lights No Stage | Lights D. C. Power | Panel $\theta$ | Panel $\dot{\theta}$ | Panel $\phi$ | Panel $\dot{\phi}$ | Panel $\psi$ | Panel $\dot{\psi}$ | Panel Vel. | Panel Accel. | Panel Alt. | Panel No. 1 Fuel | Panel No. 1 LOX | Panel No. 2 Fuel | Panel No. 2 LOX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I. Partial Loss of Thrust - One Engine (1st Stage) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| + | I-1 | | T+2.0 | T+12 | 9.72 | | | | 7.0 | | | | | | | | | | | | | | Fig. 1-1 | | | | | |
| | I-2 | | T+60.0 | T+100+ | N.D.R.T.* | | | | 65.0 | | | | | | | | | | | | | | Fig. 1-1 | | | | | |
| | I-3 | | T+100.0 | T+120+ | N.D.R.T.* | | | | 105.0 | | | | | | | | | | | | | | Fig. 1-1 | | | | | |
| | II. Total Loss of Thrust - One Engine (1st Stage) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| + | II-1 | | T+2.0 | T+6.3 | 4.02 | | | | 2.3 | | | | | | | | | | | | | | Fig. 2-1 | | | | | |
| + | II-2 | | T+15 | T+32.3 | 17.02 | | | | 15.3 | | | | | | | | | | | | | | Fig. 2-1 | | | | | |
| | II-3 | | T+90 | T+100+ | N.D.R.T.* | | | | 90.3 | | | | | | | | | | | | | | Fig. 2-1 | | | | | |
| | III. Total Loss of Thrust - Both Engines (1st Stage) or Second Stage Engine | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| + | III-1 | | T+4.0 | T+5.5 | 1.22 | | | | 4.3 | | | | | | | | | | | | | | Fig. 3-2 | | | | | |
| + | III-2 | | T+70 | T+71.9 | 1.62 | 71.0 | | | 70.3 | | | | | | | Fig. 3-1 | Fig. 3-1 | | | | | Fig. 3-2 | Fig. 3-2 | Fig. 3-2 | | | | |
| | III-3 | | T+130 | T+140+ | N.D.R.T* | | | | 130.3 | | | | | | | | | | | | | Fig. 3-2 | Fig. 3-2 | Fig. 3-2 | | | | |
| | III-4 | | T+240 | T+250+ | N.D.R.T* | | | | | On: 240.5 | | | | | | | | | | | | Fig. 3-2 | Fig. 3-2 | | | | | |
| | IV. Hardover Engine (1st Stage) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | IV-1 | | T+0 | T+0.6 | 0.32 | 0.3 | | | | | | | | | | Fig. 4-1 | Fig. 4-1 | | | | | | | | | | | |
| + | IV-2 | | T+47 | T+48.3 | 1.02 | | | 47.? | | | | | | | | | | | Fig. 4-2 | Fig. 4-2 | | | | | | | | |
| + | IV-3 | | T+60 | T+60.9 | 0.62 | 60.2 | | | | | | | | | | Fig. 4-3 | Fig. 4-3 | | | | | | | | | | | |
| | V. Staging | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| + | V-1 | | T+140 | T+142.7 | 2.42 | | | | | Off: 140.7 | | | | 142.1 | | | | | | | | | | | | | | |
| + | V-2 | | T+110 | T+119.0 | 8.72 | On: 117.4<br>Off: 117.6<br>On: 118.4 | | | | | | | On: 110 | | | Fig. 5-1 | Fig. 5-1 | | | | | | | | | | | |
| + | V-3 | | T+148 | T+150.7 | 2.42 | | | | | Off: 148.7 | | | | 150.1 | | | | | | | | | Fig. 5-2 | | | | | |

Legend:
\+ Problems Simulated During Study
++ Times Shown Are From Malfunction Onset, Minus System Sequencing Time (0.28 sec.)
* No Definite Response Time

TABLE A-1 CONT'D. MASTER LIST OF ABORT SITUATIONS

| Problem | | Time Malfunction Begins | Abort By | Required Response Time | Lights | | | | | | | | | | Panel Indicator Time History | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $\dot{\theta}$ | $\dot{\phi}$ | $\dot{\psi}$ | Chamber Press No. 1 | Chamber Press No. 2 | Tank Press No. 1 | Tank Press No. 2 | Fire Bolts | No Stage | D. C. Power | $\theta$ | $\dot{\theta}$ | $\phi$ | $\dot{\phi}$ | $\psi$ | $\dot{\psi}$ | Vel. | Accel. | Alt | No. 1 Fuel | No. 1 LOX | No. 2 Fuel | No. 2 LOX |
| VI. Tank Pressure Loss | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| VI-1 | St 1 Lox-A | T+0 | T+3.5 | 3.22 | | | | | | 2.0 | | | | | | | | | | | | | | | Fig.6-2 | | |
| VI-2 | St 1 Lox-D | T+0 | N.A.R.** | | | | | | | 10.5 | | | | | | | | | | | | | | | Fig.6-2 | | |
| VI-3 | St 1 Fuel-D | T+0 | T+7.0 | 6.72 | | | | | | 4.0 | | | | | | | | | | | | | | Fig.6-1 | | | |
| VI-4 | St 2 Fuel-C | T+0 | T+1.0 | 0.72 | | | | | | | 0.1 | | | | | | | | | | | | | | | Fig. 6-3 | |
| VI-5 | St 1 Fuel-A | T+0 | N.A.R. | | | | | | | On: 20.0<br>Off:29.0 | | | | | | | | | | | | | | Fig.6-1 | | | |
| VI-6 | St 1 Lox-A | T+10 | T+15.0 | 4.72 | | | | | | 12.3 | | | | | | | | | | | | | | | Fig.6-2 | | |
| VI-7 | St 1 Lox-B | T+20 | N.A.R. | | | | | | | 24.5 | | | | | | | | | | | | | | | Fig.6-2 | | |
| VI-8 | St 1 Lox-A | T+30 | T+36.4 | 6.12 | | | | | | 31.4 | | | | | | | | | | | | | | | Fig.6-2 | | |
| VI-9 | St 2 Lox-B | T+50 | N.A.R. | | | | | | | | 51.1 | | | | | | | | | | | | | | | | Fig. 6-4 |
| VI-10 | St 2 Fuel-C | T+60 | T+61.0 | 0.72 | | | | | | | 60.1 | | | | | | | | | | | | | | | Fig.6-3 | |
| VI-11 | St 1 Fuel-A | T+60 | N.A.R. | | | | | | | 108.5 | | | | | | | | | | | | | | Fig.6-1 | | | |
| VI-12 | St 2 Lox-B | T+65 | T+70.5 | 5.22 | | | | | | | 65.2 | | | | | | | | | | | | | | | | Fig. 6-4 |
| VII. Counter Clockwise Roll | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| VII-1 | | T+5.0 | T+25.0 | N.D.R.T. | | | | | | | | | | | Fig. 7-1 | Fig. 7-1 | Fig. 7-2 | Fig. 7-2 | | | | | | | | | |
| VII-2 | | T+5.0 | T+19.0 | 13.72 | On:17.4<br>Off:17.6<br>On:18.4 | | | | | | | | | | Fig. 7-3 | Fig. 7-3 | Fig. 7-2 | Fig. 7-2 | | | | | | | | | |
| VIII. D. C. Power Failure | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| VIII-1 | | T+12.0 | T+15.0 | 2.72 | | | 12.5 | | | | | | | 12.0 | | | | | Fig. 8-1 | Fig. 8-1 | | | | | | | |
| VIII-2 | | T+95.0 | T+100+ | N.D.R.T. | | | | | | | | | | 95.0 | Fig. 8-2 | Fig. 8-2 | | | | | | | | | | | |
| VIII-3 | | T+148.5 | T+150+ | N.D.R.T. | | | | | | | | | | 148.5 | Fig. 8-4 | Fig. 8-4 | Fig. 8-1 | Fig. 8-3 | | | | | | | | | |
| IX. Instrument Light Failures | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| IX-1 | | T+2.0 | N.A.R. | | | | | 2.0 | | | | | | | | | | | | | | | | | | | |
| IX-2 | | T+40.0 | N.A.R. | | | | | | | 40.0 | | | | | | | | | | | | | | | | | |
| IX-3 | | T+60.0 | N.A.R. | | 60.0 | | | | | | | | | | | | | | | | | | | | | | |
| IX-4 | | T+148.0 | N.A.R. | | | | 148.0 | | | | | | | | | | | | | | | | | | | | |
| X. Normal Boost | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| X | | | | | | | | | On:0.0<br>Off:148.7 | | | 148 | | | Fig. 10-1 | Fig. 10-2 | Fig. 10-2 | Fig. 10-2 | Fig. 10-3 | Fig. 10-2 | Fig. 10-1 | Fig. 10-1 | Fig. 10-1 | Fig.6-1 | Fig.6-2 | Fig.6-3 | Fig.6-4 |

**Legend:**
** No Abort Required

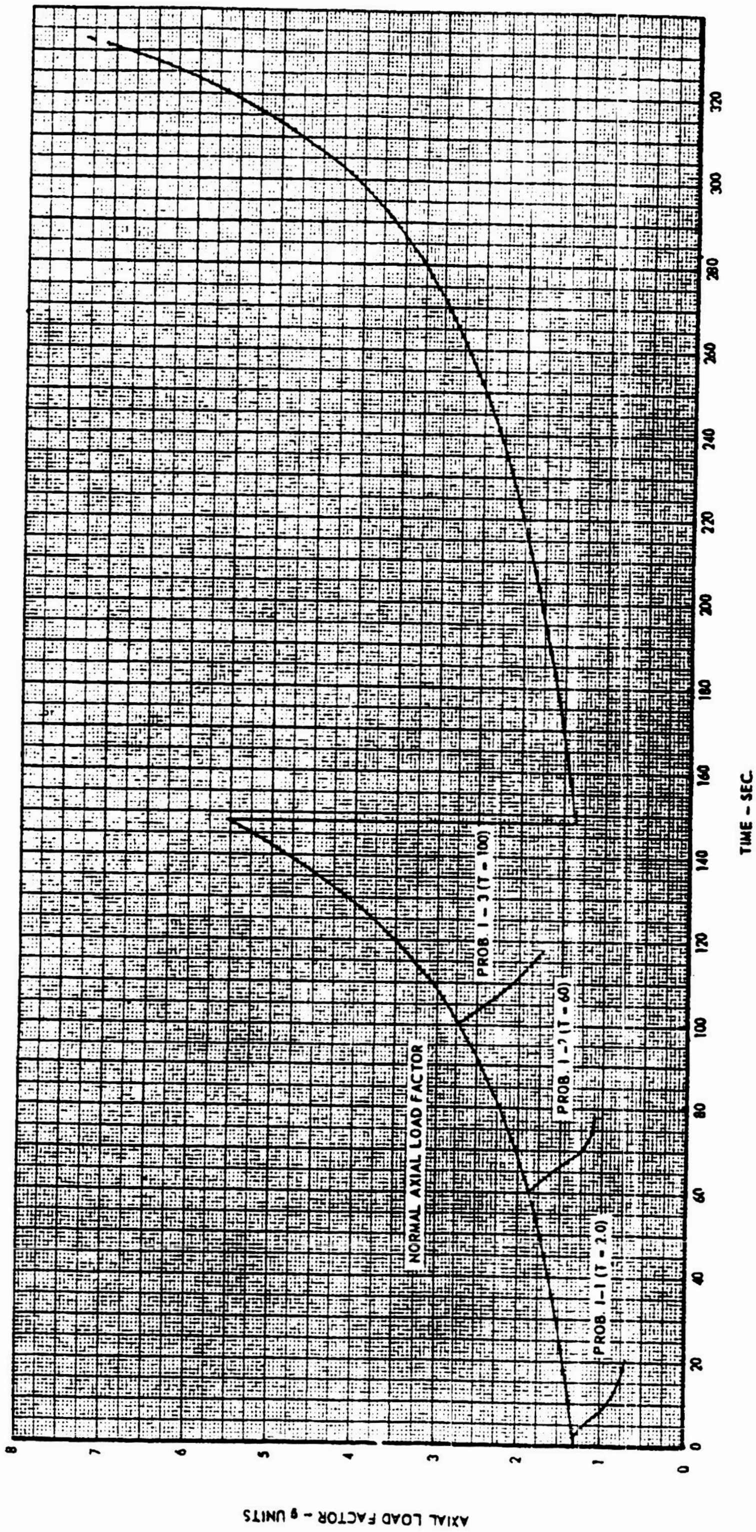


FIGURE 1–1 PROBLEM I PARTIAL LOSS OF THRUST – ONE ENGINE

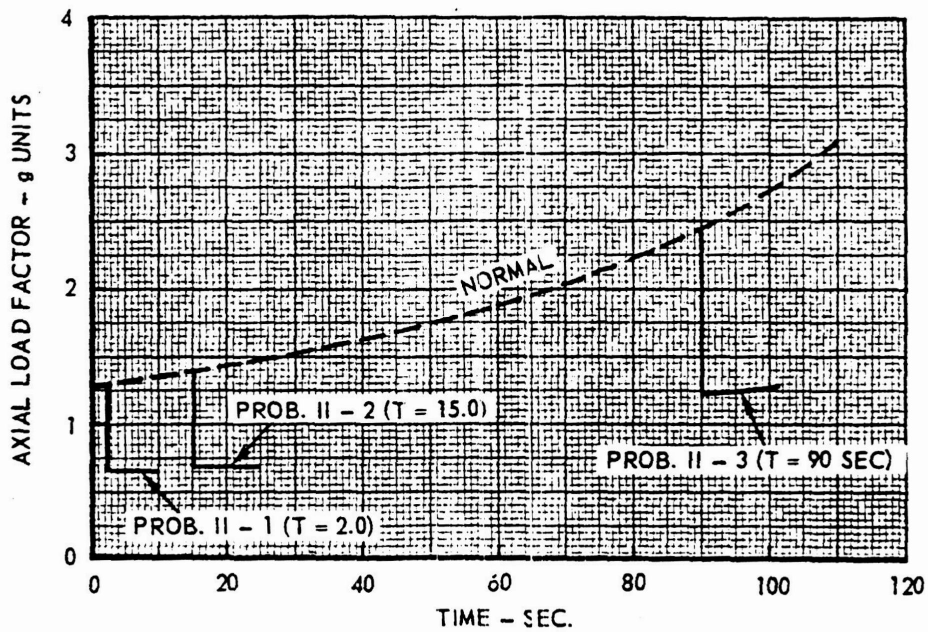


FIGURE 2 – 1 PROBLEM II – 1, 2, & 3 TOTAL LOSS OF THRUST – ONE ENGINE

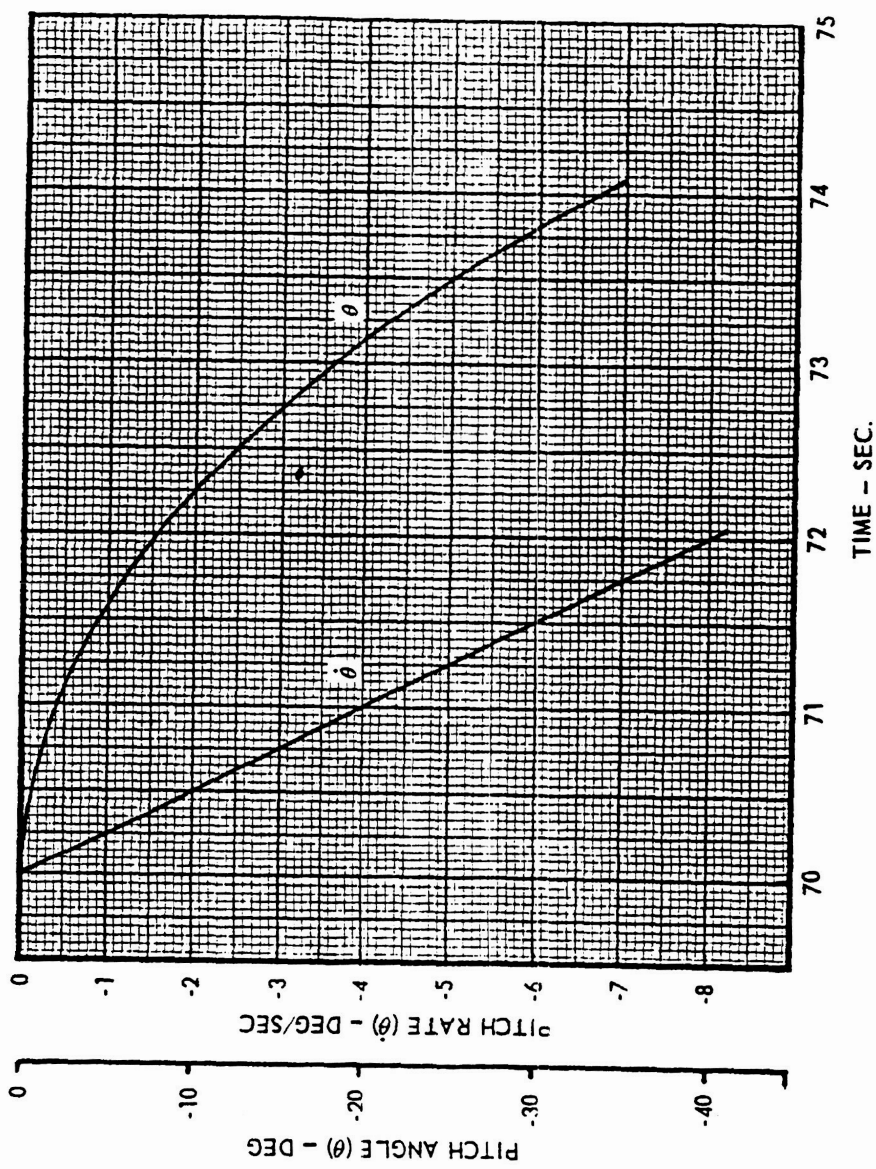


**FIGURE 3 – 1 III – 2 LOSS OF THRUST (BOTH ENGINES) @ T + 70.0 SEC.**

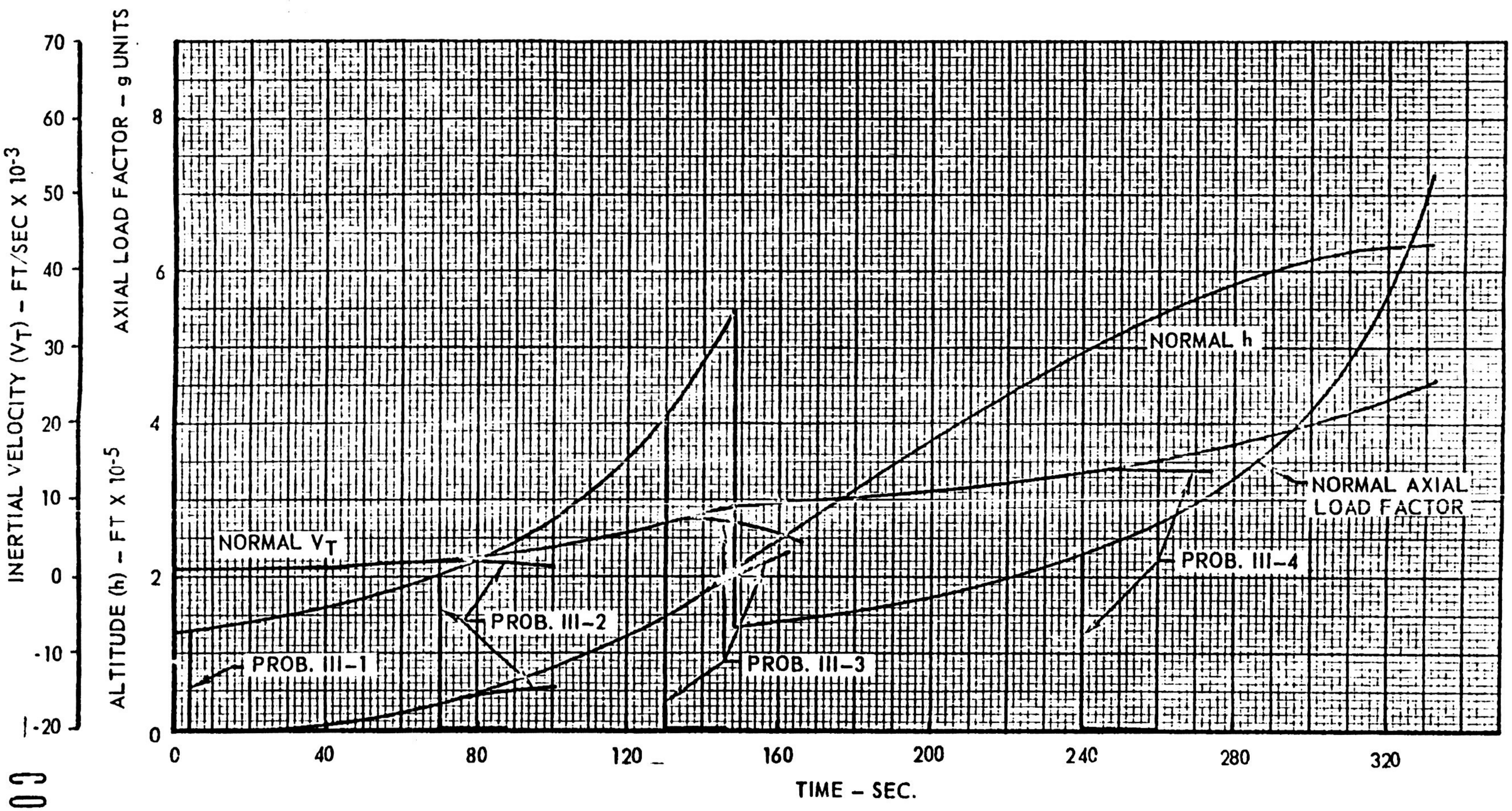


FIGURE 3 – 2 PROBLEM III COMPLETE ENGINE SHUTDOWN



CONFIDENTIA

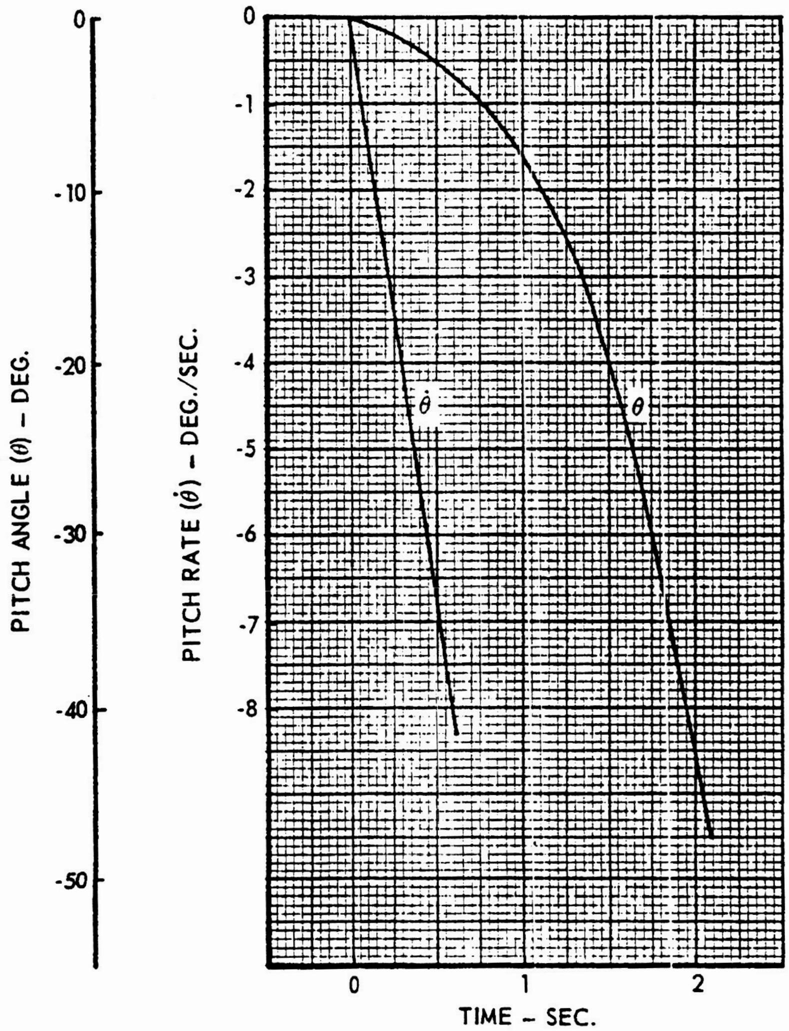


FIGURE 4–1 PROBLEM IV–1 HARDOVER ENGINE @ T = 0

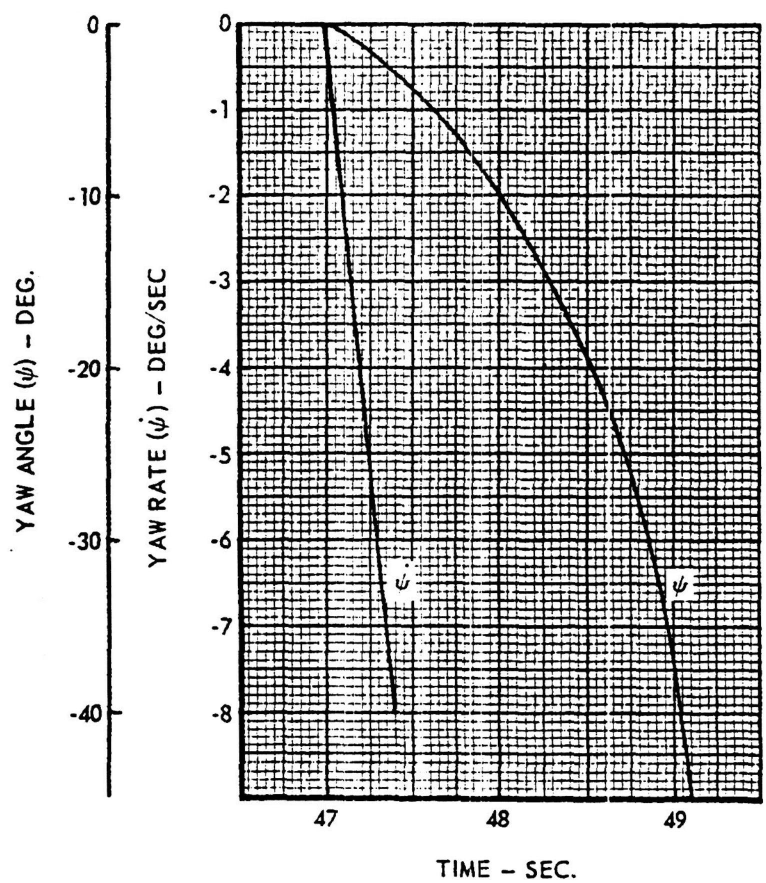


FIGURE 4–2 PROBLEM IV–2 HARDOVER ENGINE (YAW) @ T + 47

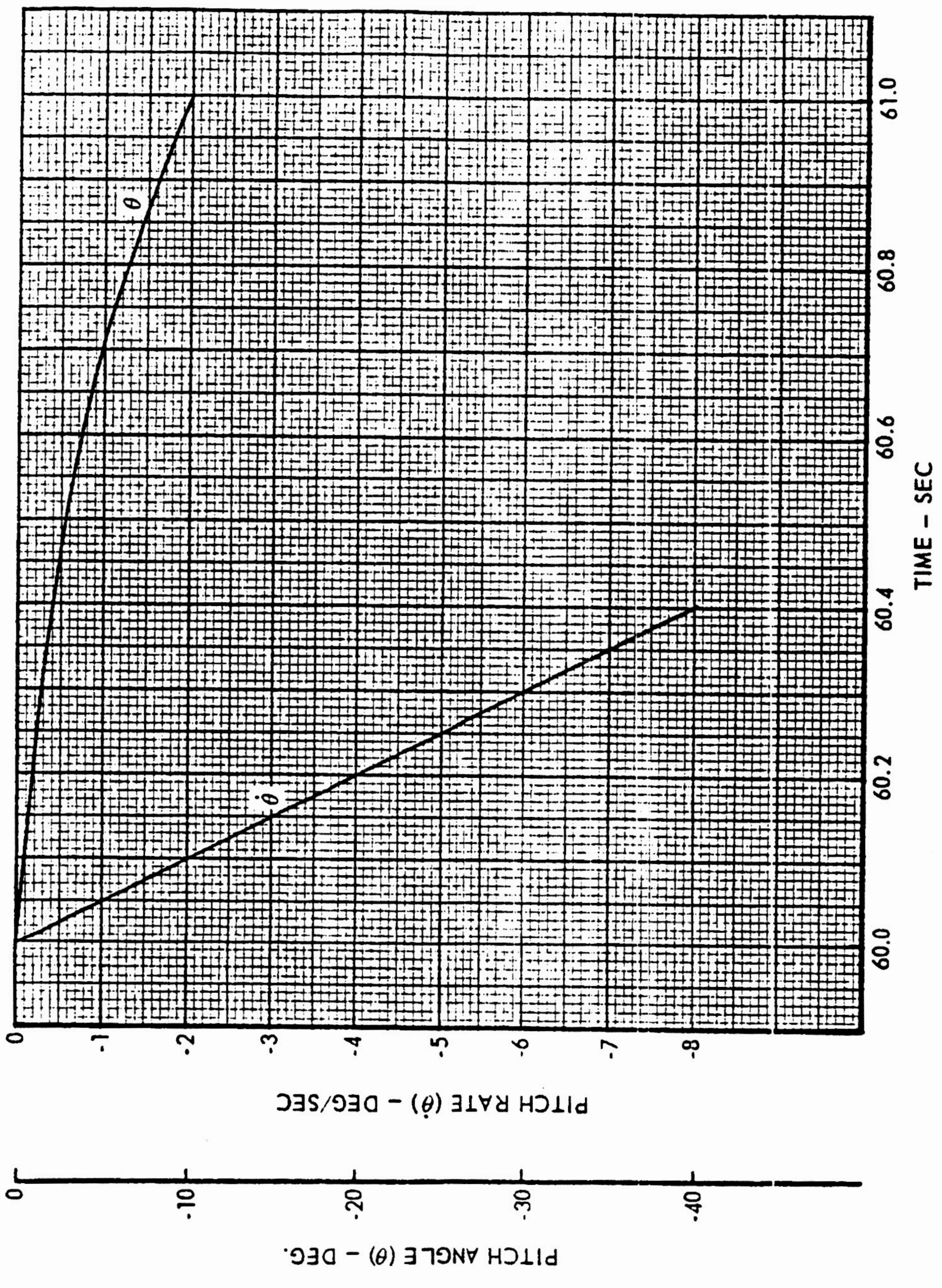


FIGURE 4-3 PROBLEM IV-3 HARDOVER ENGINE AT T + 60 (HIGH q)

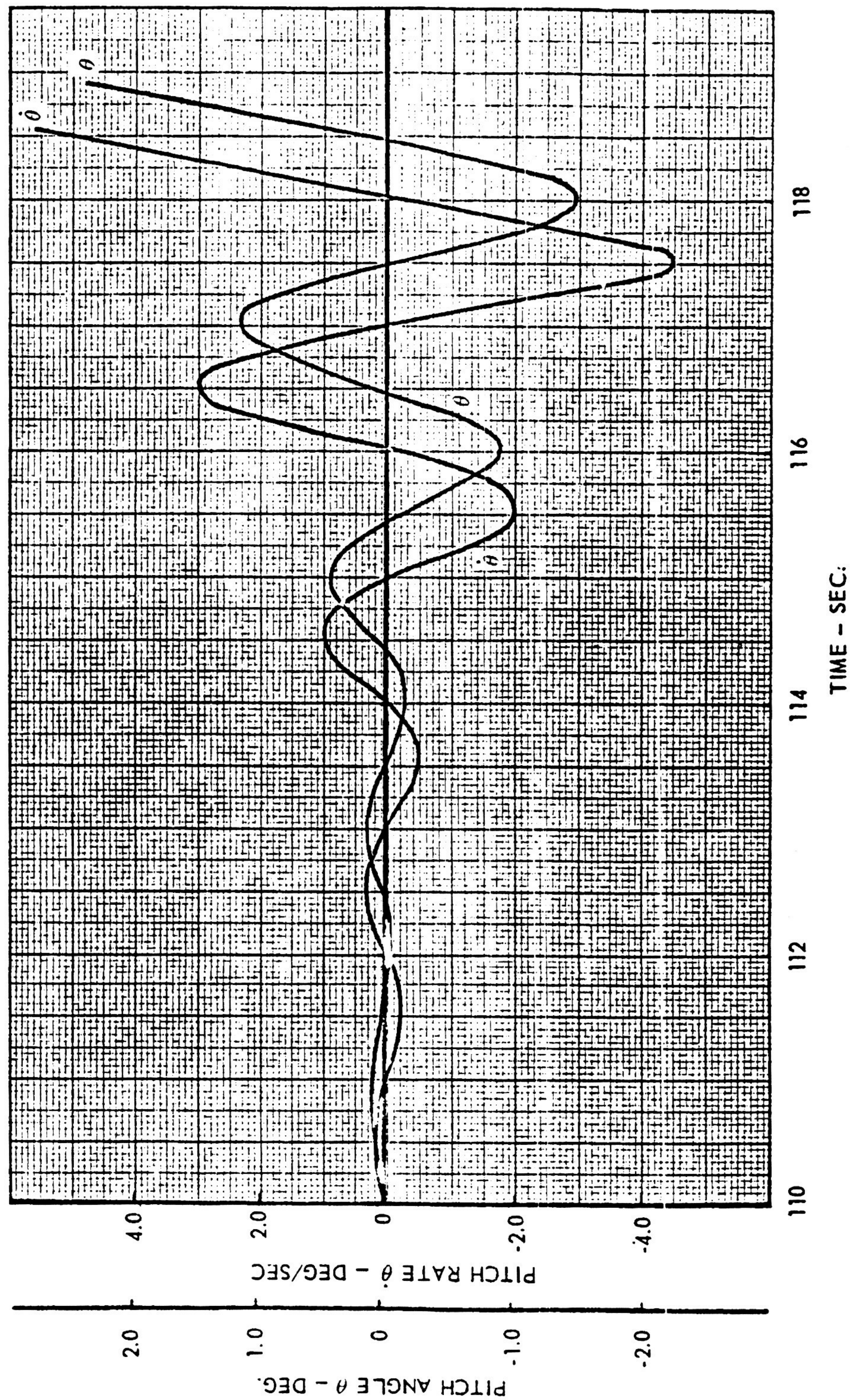


FIGURE 5 – 1 PROBLEM V –2 STAGING BOLTS BLOW EARLY @ T + 110

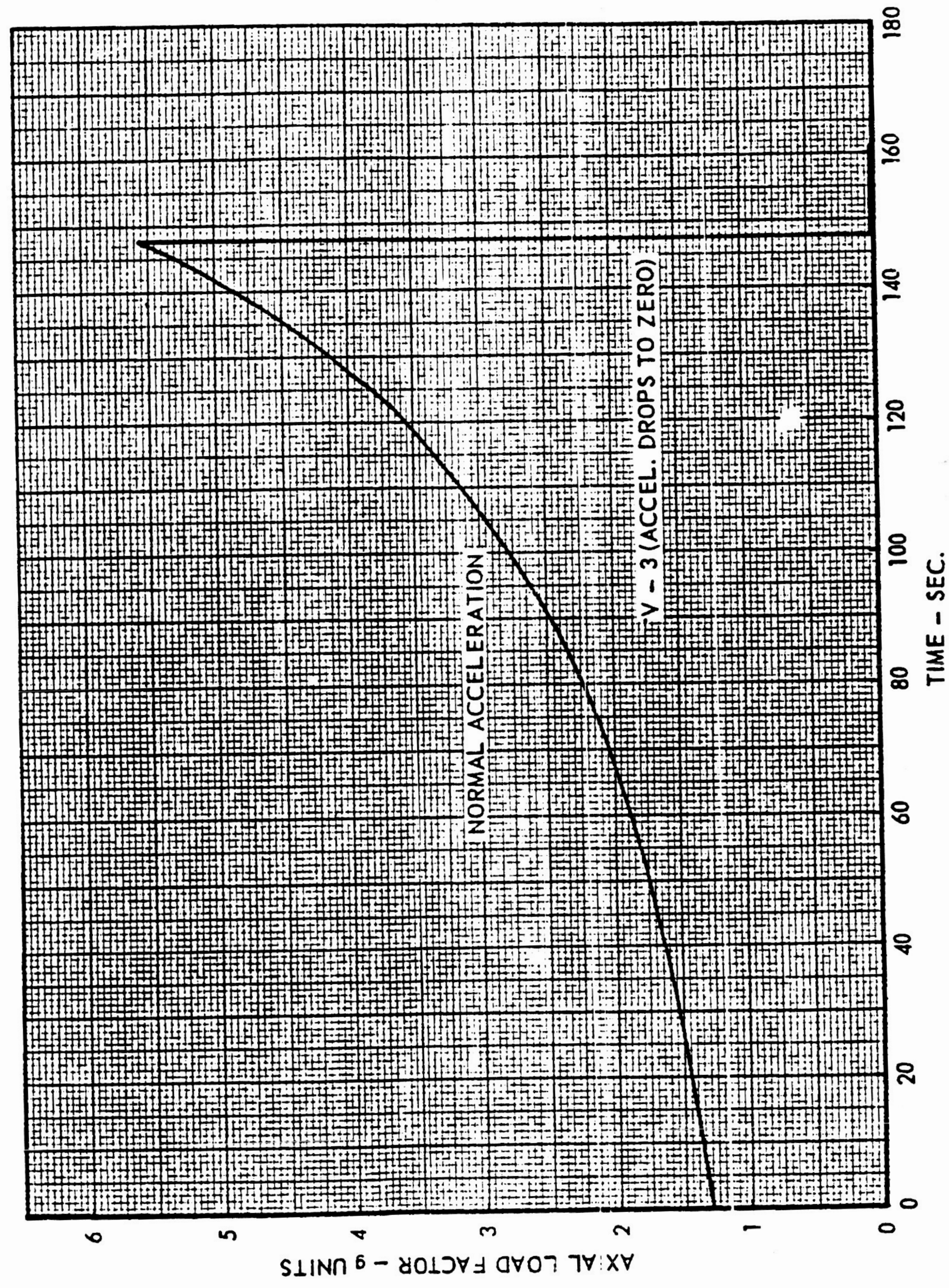


FIGURE 5 – 2 PROBLEM V – 3 STAGING BOLTS FAIL TO BLOW

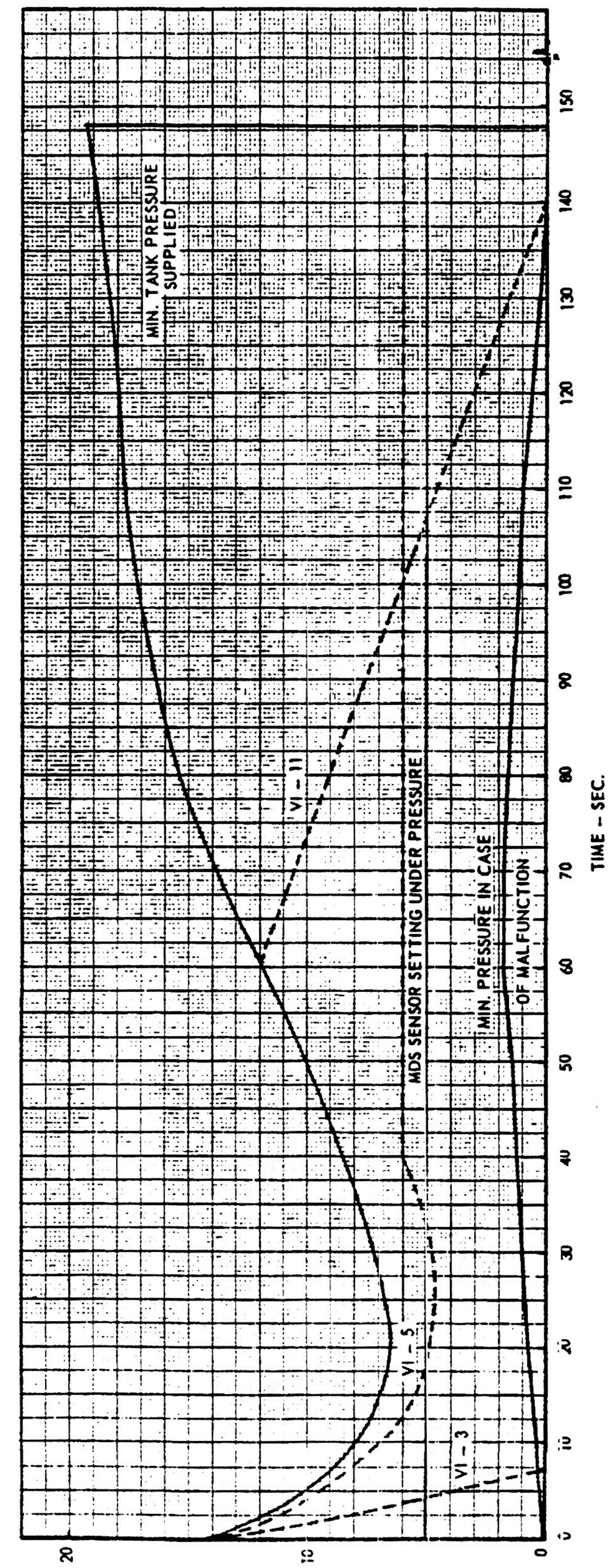


FIGURE 6 – 1 PROBLEM VI STAGE I FUEL TANK

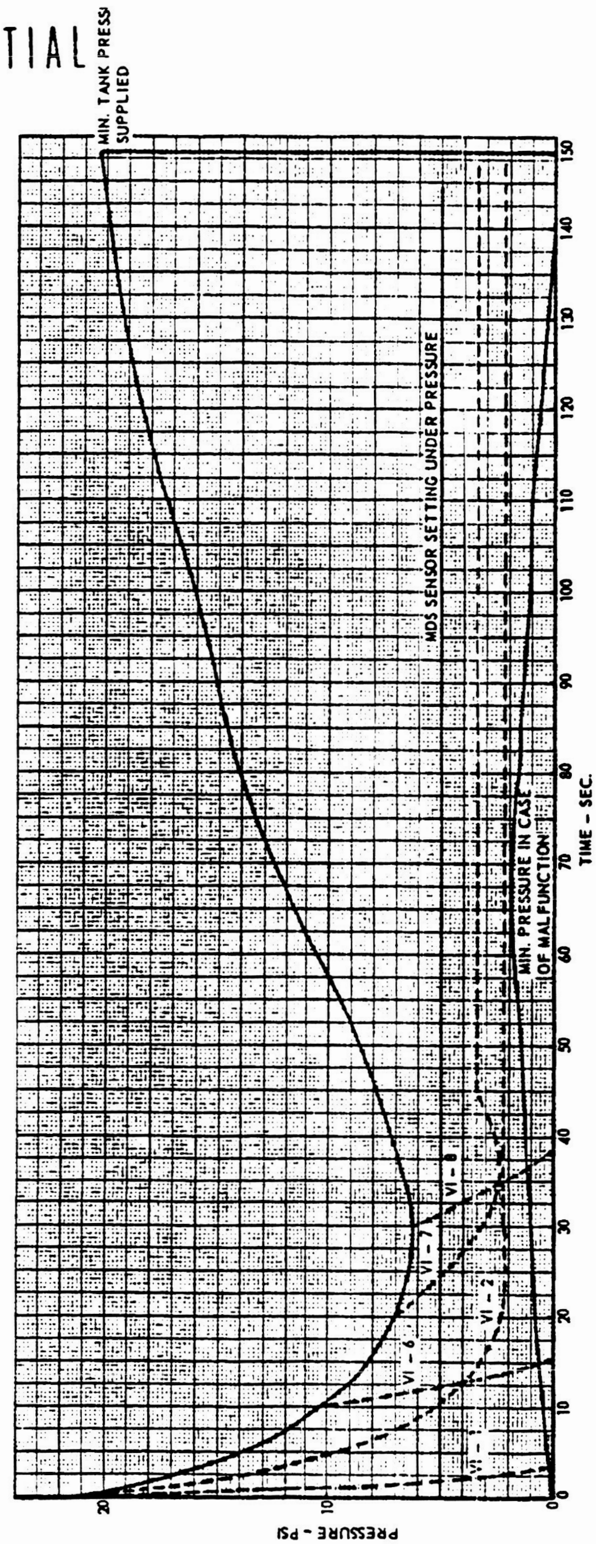


FIGURE 6 – 2 PROBLEM VI STAGE I OXIDIZER TANK

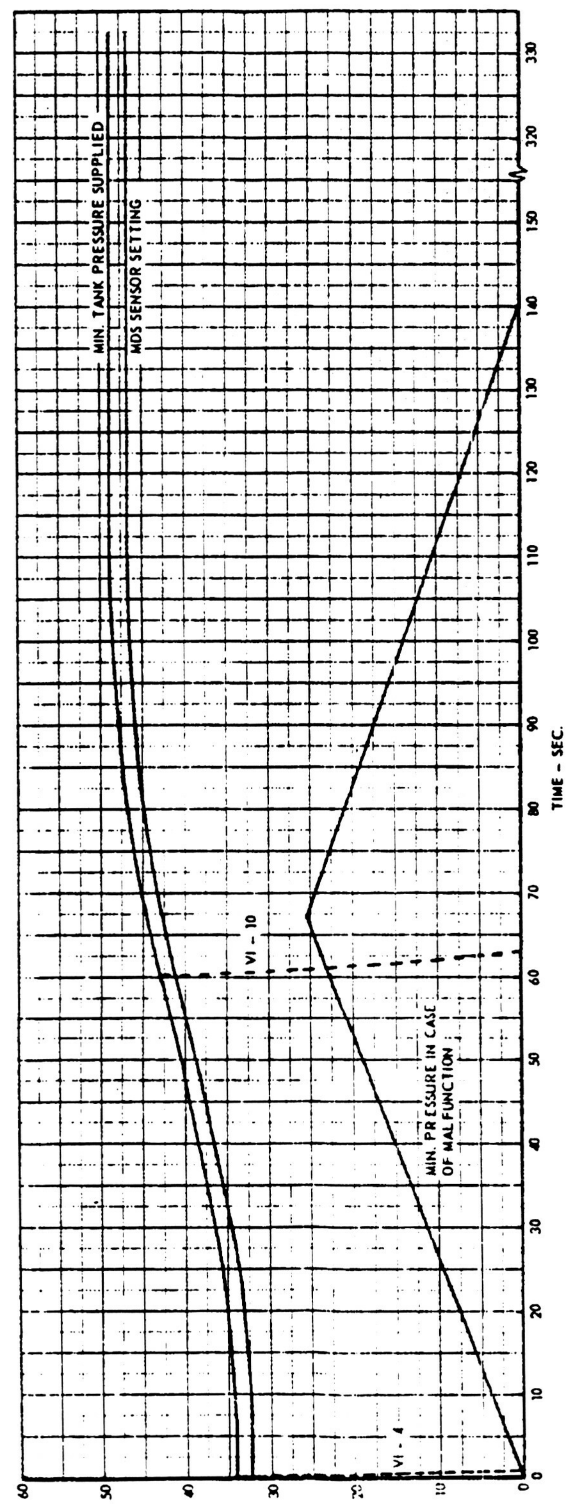


FIGURE 6 – 3 PROBLEM VI STAGE II FUEL TANK

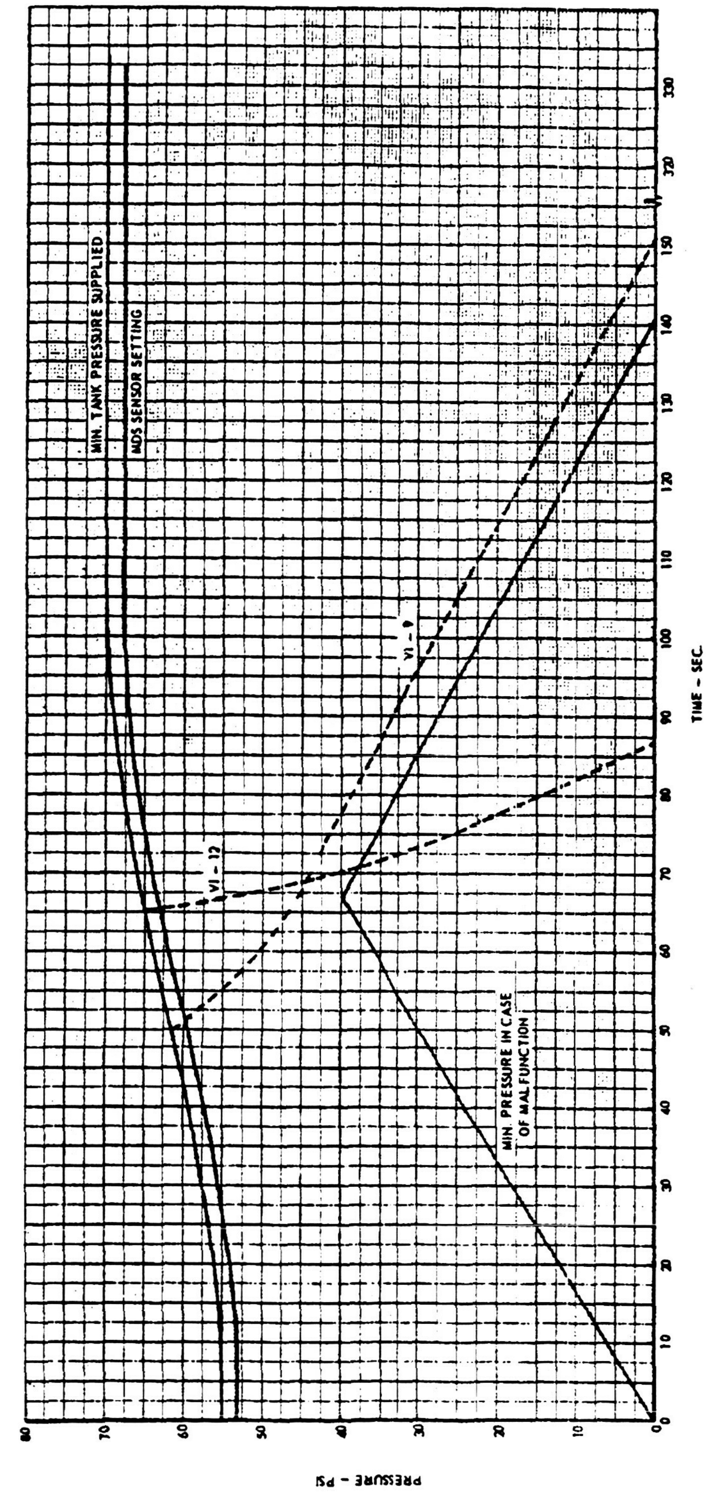


FIGURE 6 - 4 PROBLEM VI STAGE II OXIDIZER TANK

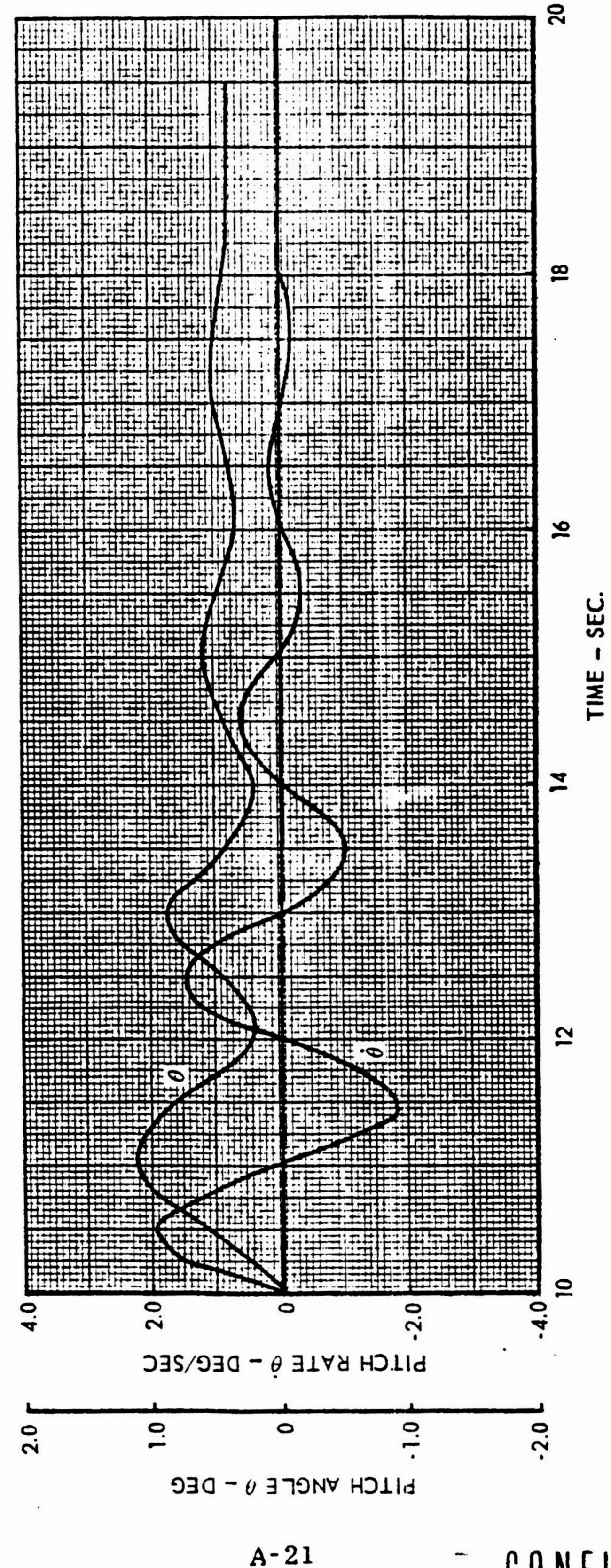


FIGURE 7-1 PROBLEM VII-1 COUNTER CLOCKWISE ROLL

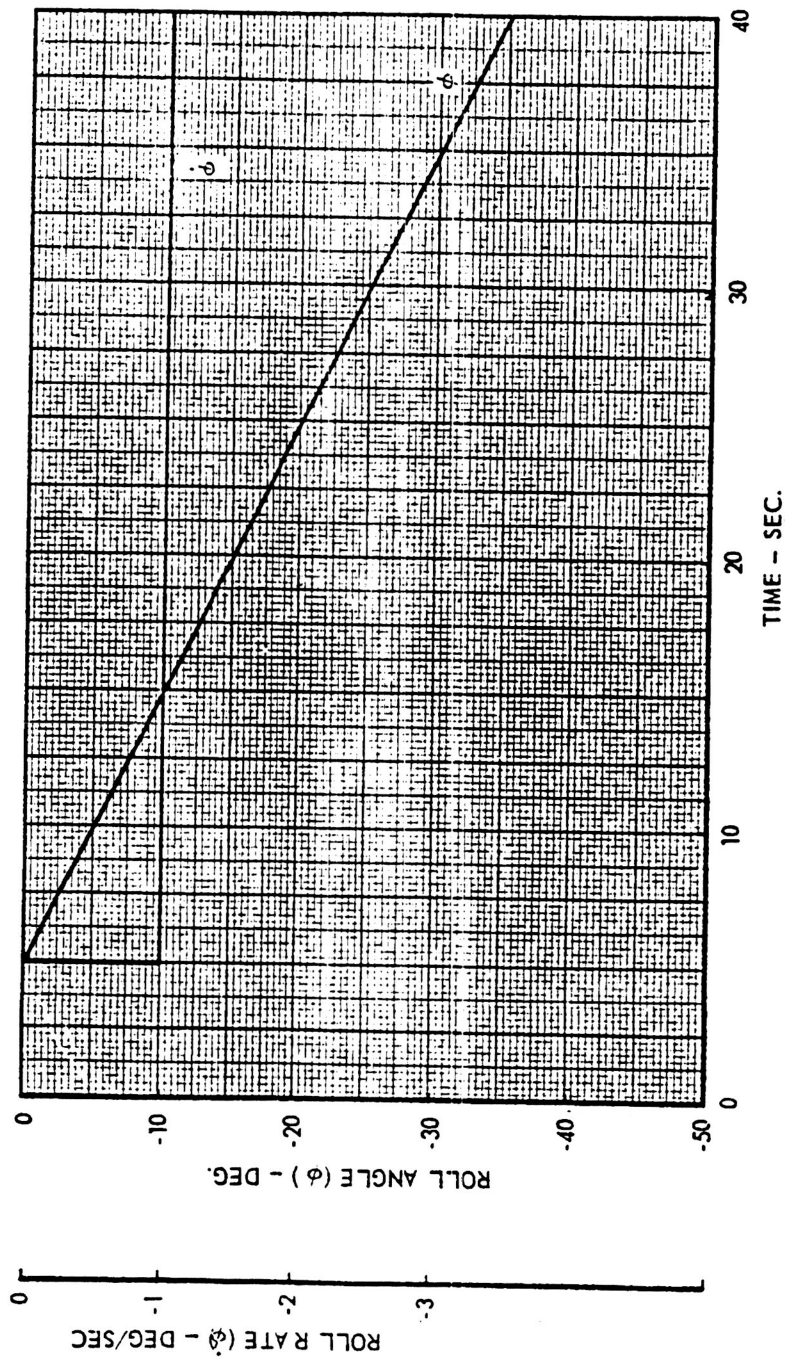


FIGURE 7 – 2 PROBLEM VII COUNTER CLOCKWISE ROLL

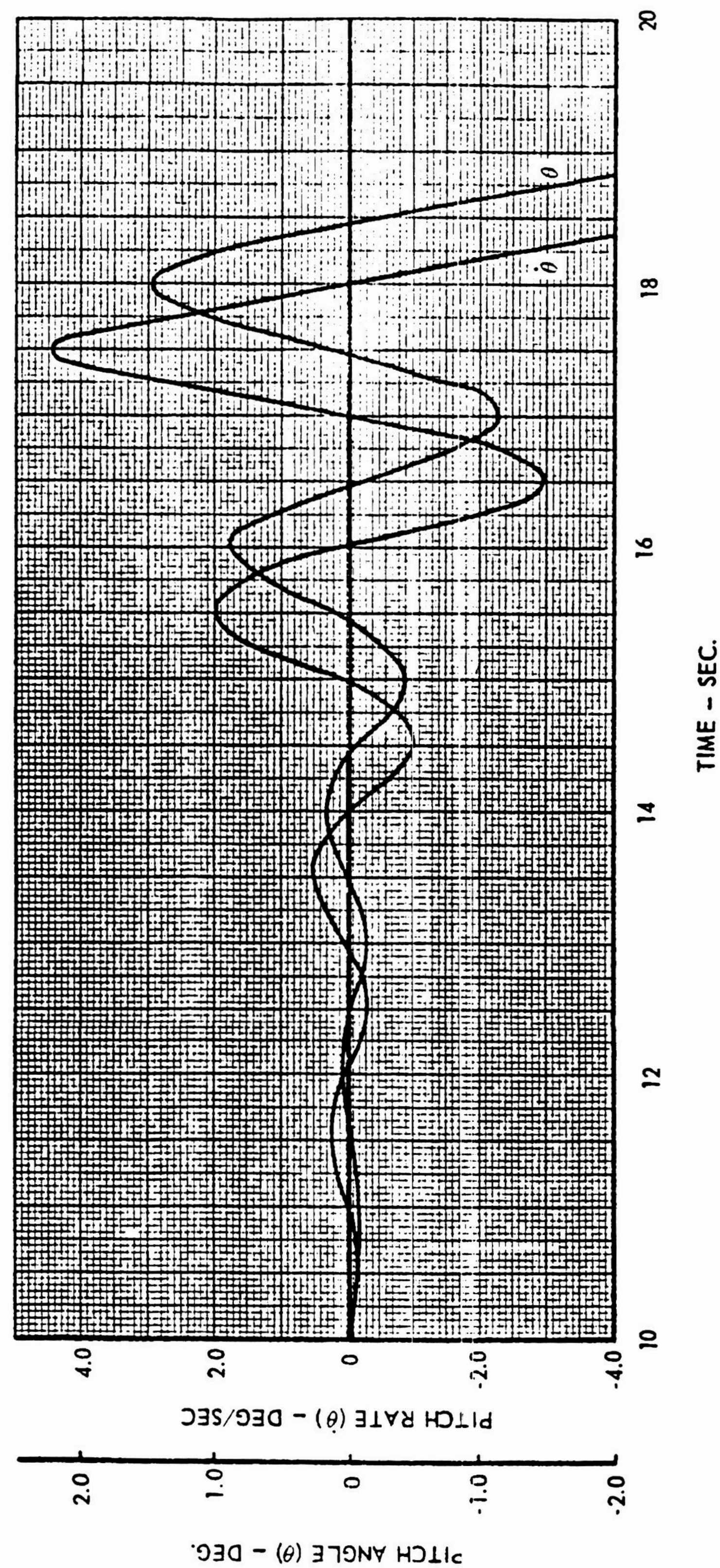


FIGURE 7 – 3 PROBLEM VII – 2 COUNTER CLOCKWISE ROLL @ T + 5.0

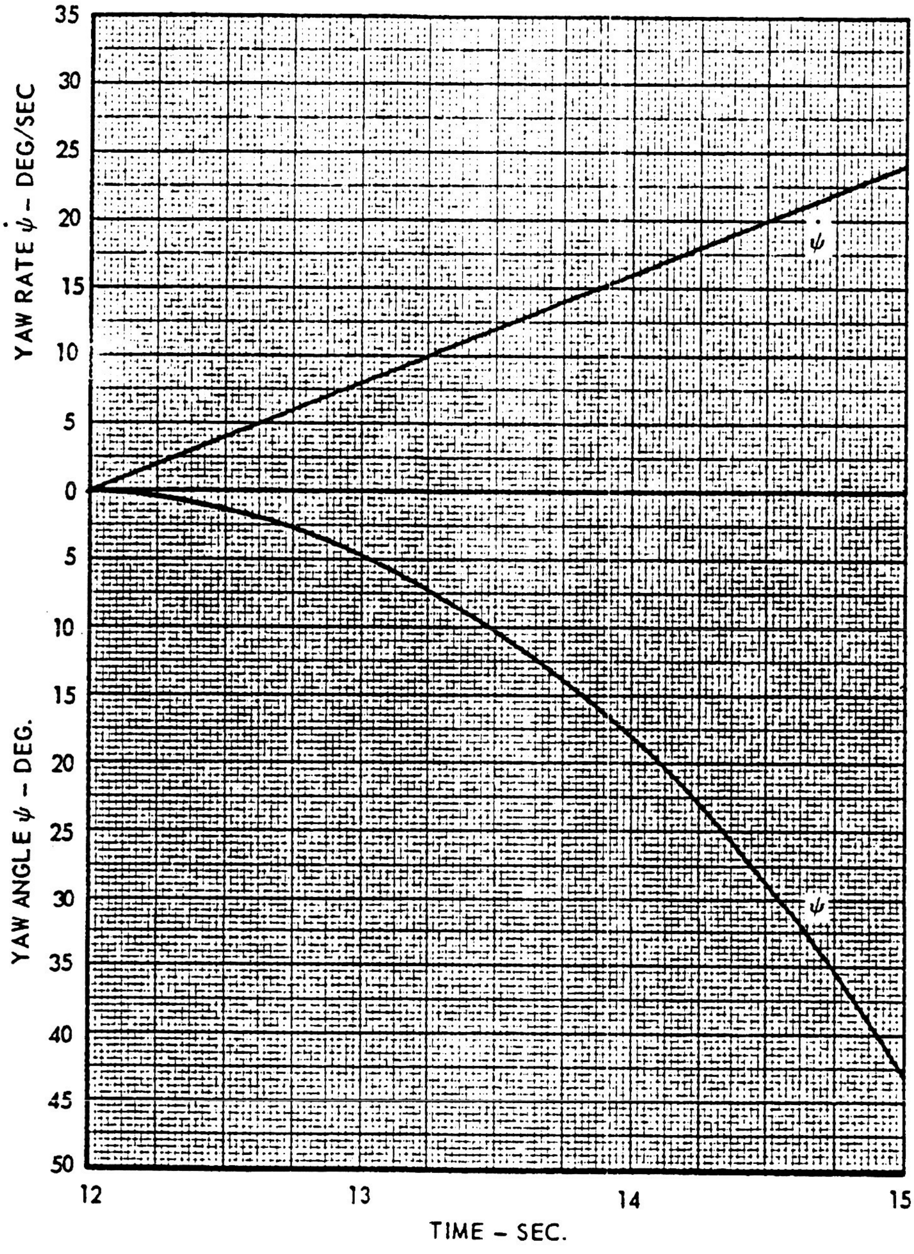


FIGURE 8 – 1 PROBLEM VIII – 1 D. C. POWER FAILURE AT T + 12 SEC.

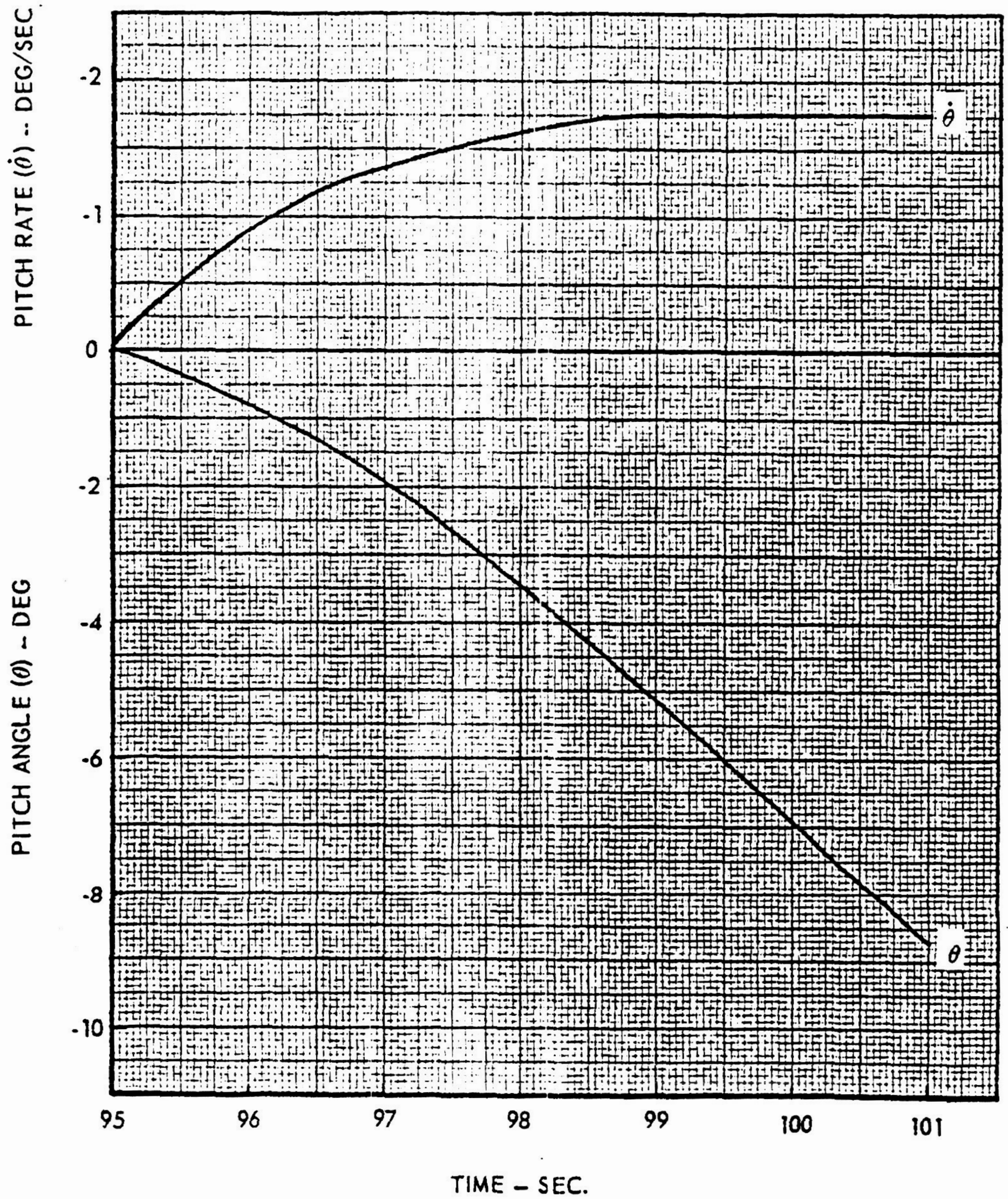


FIGURE 8–2 PROBLEM VIII–2 D.C. POWER FAILURE @ T + 95.0 SEC.

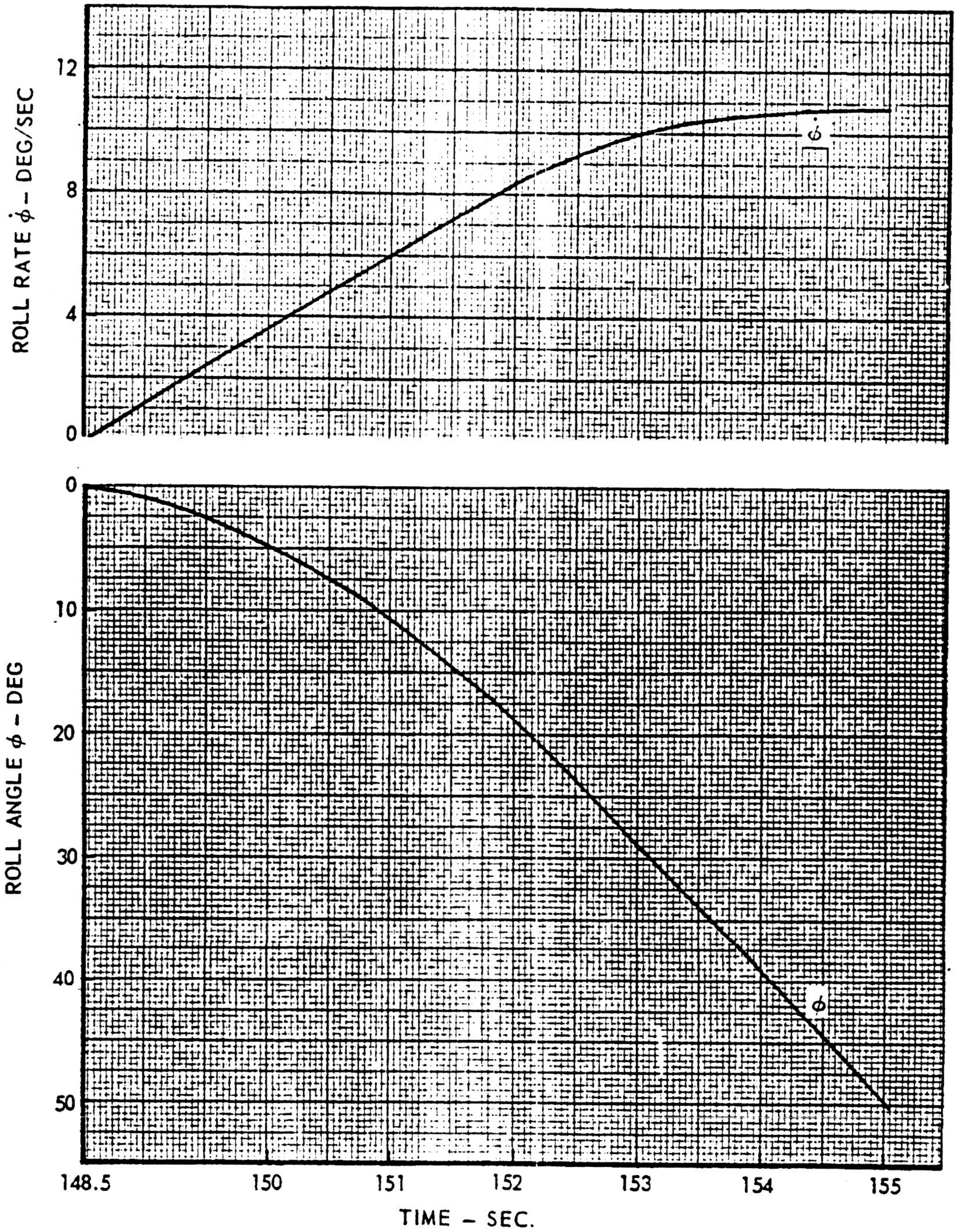


FIGURE 8 – 3 PROBLEM VIII – 3 D. C. POWER FAILURE AT T + 148.5 SEC.

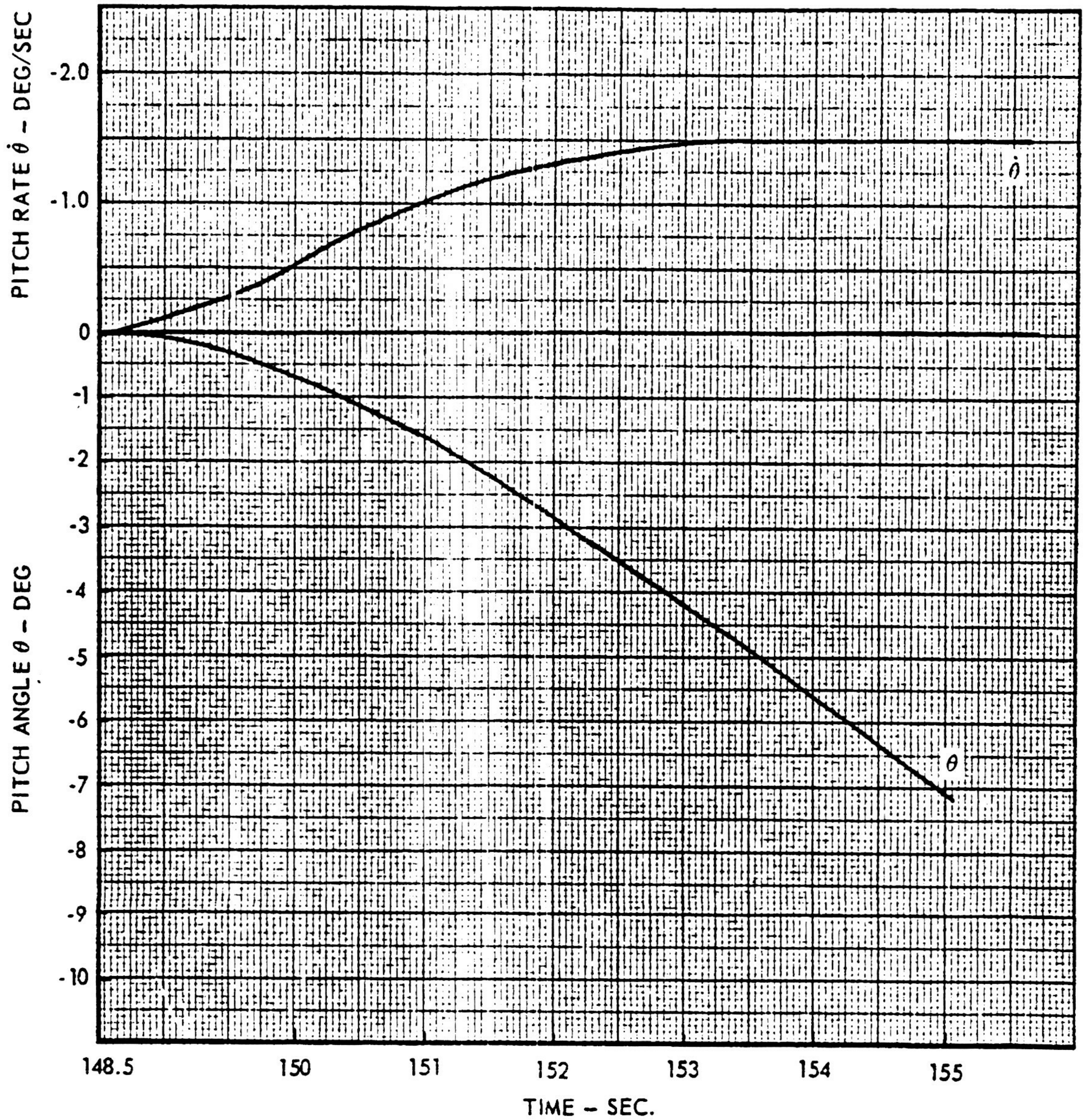


FIGURE 8 – 4 PROBLEM VIII – 3 D. C. POWER FAILURE AT T + 148.5 SEC.

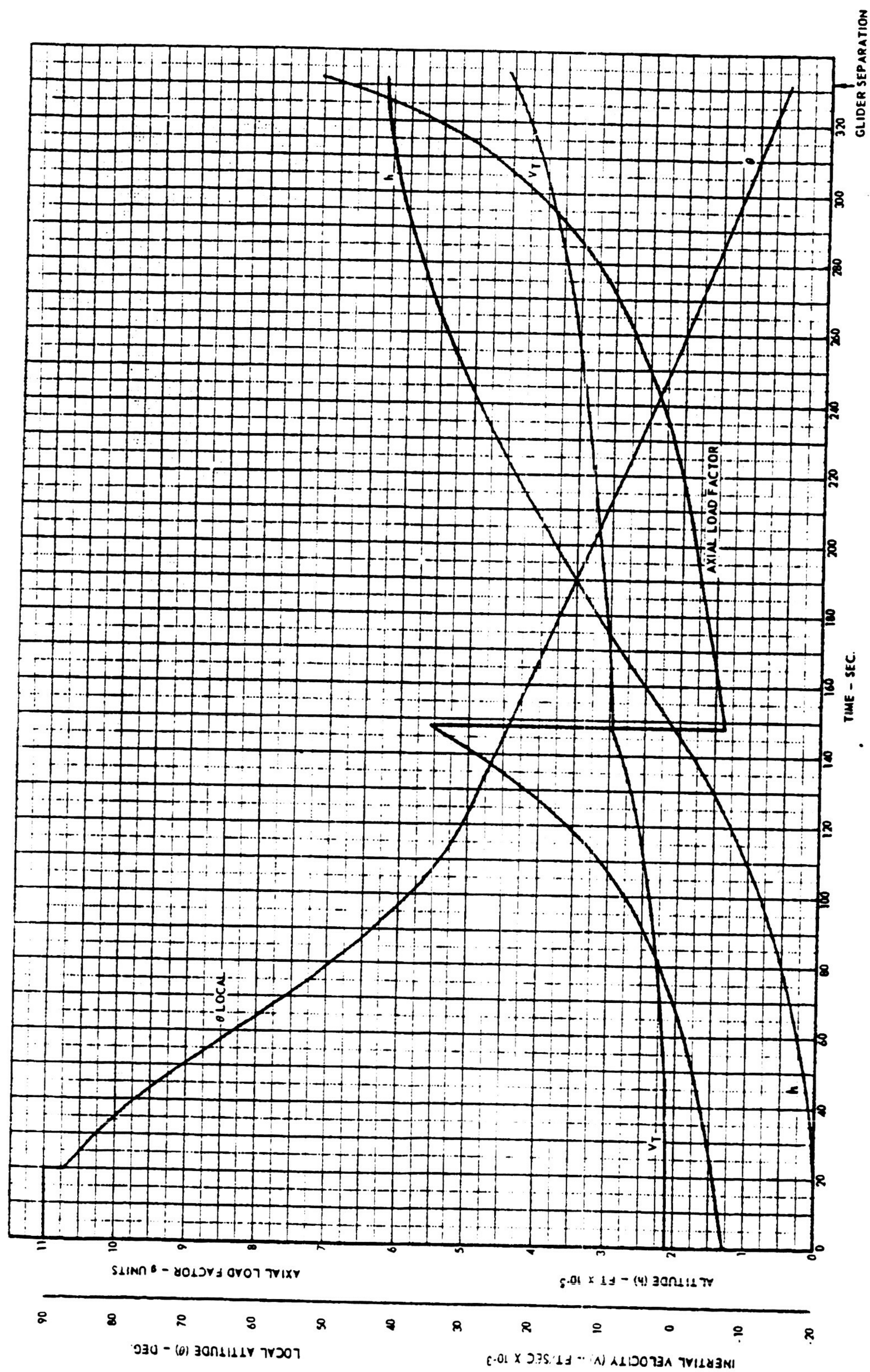


FIGURE 10 – 1 NORMAL PROGRAM

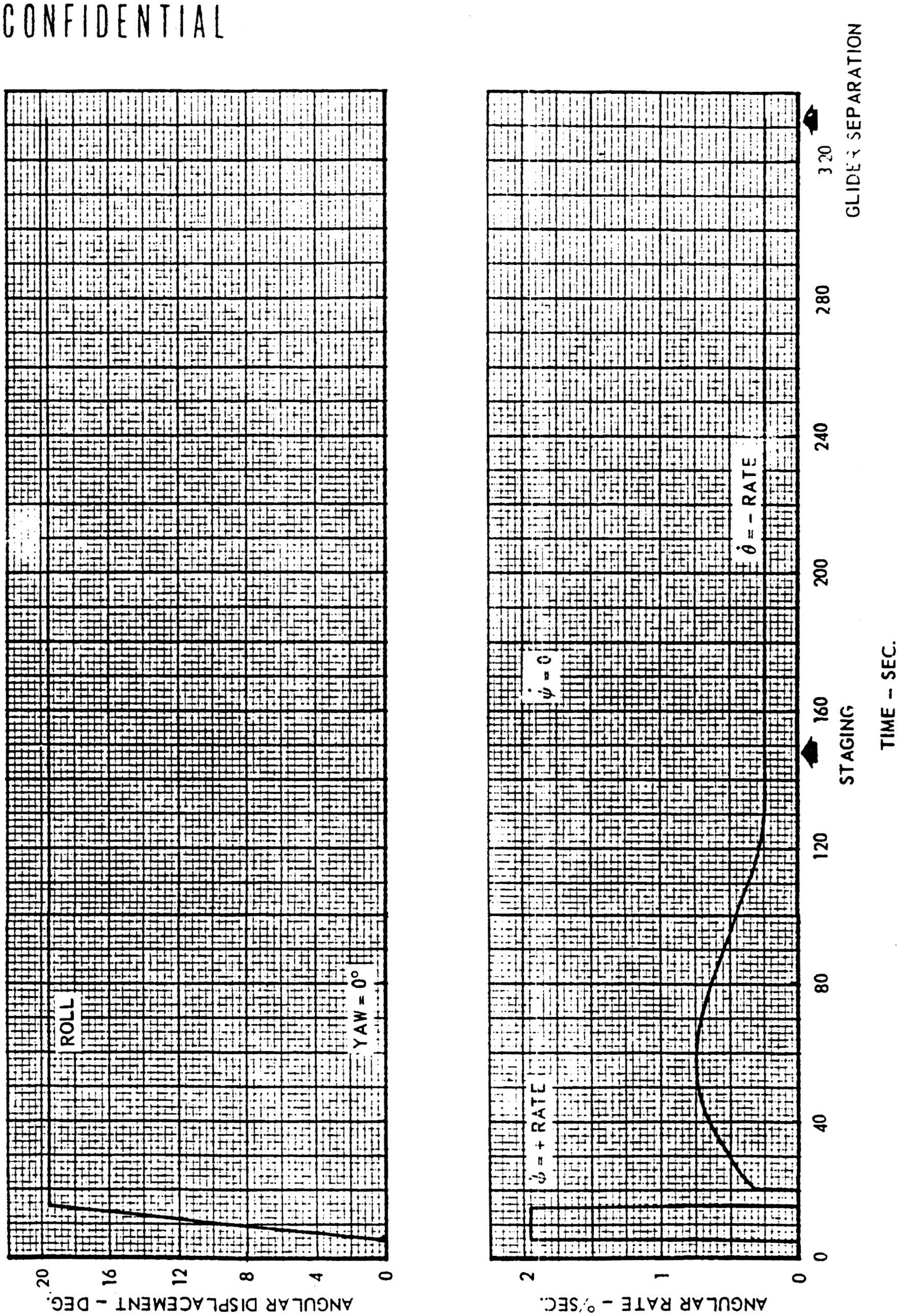


**FIGURE 10 - 2 STANDARD RUN.**